Cost of Locomotive Operation.

The Cost

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Locomotive Operation

By

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PREFACE.

In this study of the cost of locomotive operation it is hoped that a clear understanding of these expenses may be had, together with the effect of physical influences upon them. It is, of course, out of the question to determine or present absolute figures of cost that could be used without qualification, as the price of material and labor varies enormously throughout the country, as well as being subject to continual fluctuations. Thus in California and Arizona labor is from 30 to 50 per cent. more costly than in Illinois and Iowa, and here again, it is higher than in the New England States. Ordinary materials follow a similar rule, for the principal claim to increased compensation for labor is the higher cost of material products. For any locality, more or less variation also exists, if not during the same period, at least in different years, determined principally upon the general prosperity of the country at large and the law of supply and demand.

But if we cannot present absolute values of costs, we can determine the effects of different circumstances upon the cost of producing transportation, and study the methods of reducing this to the lowest limit; we can also in most cases find out the variation of costs in the form of a ratio, so that knowing the unit or base cost for a certain locality or condition, the cost under other circumstances may be closely estimated. Our investigations may therefore properly cover the following fields:

(1) The cost and value of materials, with the expense for handling and caring for them.

(2) The returns obtained by methods of using the different supplies.

(3) The effect of grade, speed, loading, etc., upon the consumption of both material and labor.

(4) The combined effects upon all the items which go to make up locomotive operating expenses.

The different items of expense are here taken up in regular order, and the effective value of the materials and methods of using them discussed, as well as the influence of physical and operating conditions upon the returns from such supplies. After these are examined individually the general effects upon the total cost are also studied, and the most economical method of operating under different physical conditions examined.

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THE COST OF LOCOMOTIVE OPERATION.

CHAPTER I.

EXPENSES CLASSIFIED.

The cost of operating locomotives represents about one-third of the total working expenses of railroads—that is, the expenses, exclusive of interest, dividends and taxes. These operating expenses, as a rule, vary from 50 to 70 per cent. of the revenue, so that the proportion of the income expended for running and maintaining the engines may be expected to fall between 17 and 23 per cent., or, in round numbers, 20 per cent.

In a paper presented to the American Engineering and Maintenance of Way Association in 1904, Mr. Berry, Chief Engineer of the Union Pacific Railroad, gave the operating expenses of that company for four years as follows:

Items.	Per cent. of whole	
Maintenance of way and structures:		
Ballast	0.28	
Frogs and switches	.35	
Protection of river banks	.03	
Repairs of roadbed and track	8.33	
Repair of snow fences and sheds	.10	
Spikes and rail fastenings	.86	
Superintendence	.55	
Renewals of rails	2.28	
Renewals of ties	3.01	
Repairs and renewals:		
Bridges and culverts	1.81	
Road crossings, etc	.32	
Buildings and fixtures	1.99	
Telegraph	.15	
Stationery and printing	.01	
		20.07

Forward		20.07
Maintenance of equipment:		
Superintendence	0.63	
Repairs and renewals:		
Locomotives	*10.19	
Passenger equipment cars	2.07	
Freight cars	5.32	
Work cars	.51	
Shop machinery and tools	1.03	
Stationery, etc.	.80	
		20.55
Conducting transportation:		
Superintendence	1.50	
Engine and roundhouse men	*10.10	
Fuel for locomotives	*10.80	
Water, oil, waste, etc., locomotives	*1.36	
Train service	5.55	
Train supplies and expenses	1.91	
Switch, flag and watchmen, etc	2.36	
Telegraph expenses	2.44	
Station service and supplies	5.62	
Car mileage	.61	
Hire of equipment	.04	
Loss and damage—property and personal	1.88	
Advertising, rents, etc	4.66	
Stationery and printing	.53	
		49.36
Taxes paid		5.64
General expenses		4.38
Grand total		100.00
Average cost per train-mile for the 4 years considered		$1.17

Here, it will be seen, the items that make up the actual charges of locomotive operation amount to 32.45 per cent., including taxes (these items being marked with a star *), or about 34 per cent., when taxes are not included. While these figures are taken from a single line, they represent quite fairly the general trend of operating expenses for the principal railroads of this country, and they also indicate the important part which locomotive operation plays in the expenses as well as the receipts of railroads. On large systems the total is a vast amount, running into many millions yearly, yet in spite of this fact, there is little *definite* information regarding the various

indivdual items of expense, when by "definite" we mean the actual expenditure per unit of work accomplished. It is true that we can divide the total figures of any one account by the engine mileage, train mileage, ton mileage, or any other factor, and obtain a unit cost for the system or division, but this will not differentiate the up-hill and level work, or the slow and time freights, nor can we gather any idea of the cost per horse-power developed per hour, nor the effects of grade, speed, loading, etc.

We can further make comparisons between the monthly performances of locomotives, in order to determine whether the coal consumption per engine or ton-mile is increasing or diminishing, but if it be increasing, it is often difficult to assign a reason for the same, although a perfectly logical one may exist. It is on account of these very difficulties that this work is undertaken, with the hope of clearing up, in part at least, the uncertainties arising from variable physical and traffic conditions, and enabling railroad officials to prognosticate and explain some of the seemingly unaccountable increases and decreases in the cost of operation. In order to accomplish this it will be necessary to study each of the different items separately, and to examine their relative and actual values for the purposes to which they are applied, as well as the effect of physical and operating conditions of various kinds and magnitude. For this purpose the expenses will be classified under the general heads of: (A) supplies; (B) maintenance; (C) service; and these will be subdivided into the individual items enumerated below:

(A) Supplies.—(1) Fuel; (2) water; (3) lubricants; (4) waste; (5) tools; (6) miscellaneous.

(B) Maintenance.—(7) General repairs; (8) running expenses; (9) renewals.

(C) Service.—(10) Engineers; (11) firemen; (12) hostling and turning; (13) cleaning fires; (14) wiping; (15) inspecting; (16) firing-up.

These different items must be examined in regard to all phases of quality and quantity which affect the cost of operation, and also as affected by grade, speed, loading, weather, etc. After investigating the individual varieties of the different items, we must study their combined influence upon the subject of our discussion, and determine the most economical method under given fixed traffic or physical conditions.

CHAPTER II.

FUEL.

As in the case of the railroad previously quoted, this is generally the largest item of expense which has to be met, and it is also one of the most difficult to control. At the very outset we find ourselves confronted by the fact that much that is bought and sold as fuel, is not fuel at all. We will therefore first consider the question of quality of fuel.

QUALITY.

The various kinds of fuel in use upon locomotives are practically without number, and each one has a different steam-making value. From undried, rain-soaked wood to mineral oil, representing the poorest and the best of fuels used in this country, there are an unlimited number of grades sold at a practically unlimited number of prices. The steam-making value of a fuel is determined by its chemical composition, and by the number of "heat units" which it will give out when uniting with the oxygen of the air in the process termed "burning," and the latter is dependent upon the former. The fuels used depend almost entirely upon the quantity of carbon and of hydrogen which they contain, along with oxygen, for their heating value, although the latter element (oxygen) is merely a supporter of combustion, and it is usually considered negative in its action. For instance, the formula of Dulong, which is ordinarily used to determine the number of British thermal units (B.t.u.) from the analysis is expressed as follows:

$$\text{B.t.u.} = 14{,}500\ C + 62{,}100 \left(H - \frac{O}{8}\right) \quad \ldots (1)$$

where C, H and O represent the quantities of carbon, hydrogen and oxygen in a given amount of fuel, ordi-

narily, one pound. For every B.t.u. so calculated we should theoretically be able to raise one pound of pure water one degree Fahrenheit in temperature, though the efficiency of the boiler, being less than unity, prevents our realizing ordinarily more than two-thirds of this heat. Now, when we compare the analysis of ordinary wood and Texas oil, we see at once the great variation in heating value due to the proportions of carbon, hydrogen and oxygen.

	Percentage in	
Constituent.	Ordinary wood.	Texas oil.
Carbon	37.50	84.60
Hydrogen	4.50	10.90
Oxygen	30.75	2.90

In the oil the carbon and hydrogen are over twice as great, and the oxygen 10 times less than in wood, so that we are quite prepared to find the heat units in a pound of wood to be in the neighborhood of 5,800, and in oil 18,800—over three times as great.

Most fuels—and especially coals—contain large quantities of non-combustible matter, commonly termed *ash*, the amount varying from 1 or 2 per cent. up to 30 per cent., the western coals, as a rule, containing greater proportions than the eastern coals. This material is so much waste, as it generates no heat, but must itself be heated up to the temperature of the fire-box before it falls into the ash-pan. Occasionally small samples of a ton or two will contain still larger percentages of slate, *rock* and materials that might make fair ballast for the track, but are very discouraging to the enginemen, especially when the train is behind time and trying to recover its schedule. Such material is also usually paid for at the contract price for coal. These cases are extraordinary, but the author has known them to occur more than once, generally accompanied by complaints from the transportation department of the failure of the engine to do the work expected of it.

In order to give some tangible idea of the relative values of various kinds of coal, and also of the uselessness of making comparisons between services performed when the fuel is not identical, the following table is introduced. Of course, it must not be understood that the coals mentioned will always show as indicated when tested, but the values given in B.t.u. are selected from different authorities. The last column gives the number of ton-miles in freight service that would ordinarily be made over such a road as the Chicago & North-Western to the pound of coal burned, and is based on results actually obtained with Illinois coal, averaging perhaps, about 10,000 B.t.u. per pound.

From the above we see that some coals will generate twice as much heat as other coals, and consequently will do twice as much work. On some large roads many different kinds of coal are used. At times this is confined to certain specific divisions, and at other seasons it is indiscriminately mixed, so that one month the fuel may be much poorer than another. This will immediately cause an increased coal consumption per 100 ton-miles, and if this point is not carefully watched, it may be difficult to answer some of the unpleasant questions which are sure to follow. Some roads have made a practice of inspecting large proportions of the coal purchased, and recording information regarding the quality, etc., so that the matter can be promptly taken up for adjustment if the quality depreciates. However, even if the coal has a good appearance, but comes from another locality, it cannot be stated definitely without tests or analyses whether it is as good a steam generator as that from some other mine. The purchasing agent can generally help out in the matter by ordering from those mines which produce the greatest heat units in a pound of fuel, but then coal mining is a particularly uncertain proceeding, liable to be interrupted at any time by strikes or physical disturbances, when the buyer must look elsewhere, and generally the urgency is

THERMAL VALUE OF COALS.

Kind.	State.	Locality.	B. t. u. per lb.	Ton-miles, per lb.
Anthracite	Pennsylvania		14,000	7.00
Anthracite, pea	"		12,300	6.15
Semi-bituminous	"	Connellsville	13,300	6.65
Semi-bituminous	West Virginia	New River	14,000	7.00
Bituminous	Pennsylvania	Pittsburg	13,000	6.50
"	"	Youhgiogheny	13,000	6.50
"	Ohio	Hocking Valley	13,400	6.70
Block	Indiana	Brazil	14,000	7.00
Bituminous	Illinois	Streator	11,400	5.70
"	"	Mt. Olive	11,700	5.85
"	"	Macoupin County	9,800	4.90
"	"	Perry County	9,800	4.90
"	"	St. Clair County	10,000	5.00
"	"	Mercer County	13,000	6.50
"	Iowa	Good Cheer	8,700	4.35
Cannel	Kentucky		14,000	7.00
Bituminous	Arkansas	Huntington County	11,800	5.90
Lignite	"		9,200	4.60
"	Colorado		13,500	6.75
" slack	"		8,500	4.25
"	Texas		12,900	6.45
Bituminous	Kansas	Burlingame	10,500	5.25
"	"	Cherokee	13,400	6.70
"	"	Frontenac	12,100	6.05
"	"	Leavenworth	11,100	5.55
"	"	Leavenworth, nut	6,600	3.30
"	"	Osage City	10,700	5.35
"	Missouri		12,200	6.10
Lignite	Iowa		8,700	4.35
"	Wyoming		10,400	5.20
"	Utah		11,000	5.50

so great that little opportunity is afforded to make a careful selection, and he is glad to get whatever can be shipped promptly—sometimes even to take back coal that has been once rejected on account of absence of lump or presence of slate. Under such circumstances there is only one thing to be done—make the best of it. Recourse has been had to coke forks to sort out the lumps for passenger engines, leaving the slack for freight and switch engines, in order to keep the passenger trains on time. It is needless to again state that such a condition will very materially affect the amount burned per ton-mile.

PRICE.

Ordinarily the price of a commodity is supposed to give some indication of its quality, but with coal this is seldom the case. The costs of production and transportation are alone responsible for the prices charged, and neither of these, as a rule, has any direct bearing upon the quality. It is true that the Pennsylvania anthracites, which are very rich in heat units, require expensive machinery for their preparation; on the other hand, the West Virginia semi-bituminous and the Pittsburg bituminous cost about the same to mine as the inferior coals of Kansas and Iowa.

Then again, it costs no more to haul a ton of good coal than a ton of poor coal, so that the distance from the mines producing the higher grades is the only indication of the comparative value of this fuel. Certain localities are noted for the fine grades of coal furnished, although there may be adjacent mines very much inferior. This is particularly true of the West Virginia fields, for while the New River and Pocahontas mines are well known as the best in the country, the coal produced in the western part of the state is much less desirable.

This state of things accounts for the fact that we will often be able to obtain a good quality of coal at a lower

figure than a poorer product. The Norfolk & Western and the Chesapeake & Ohio, running in close proximity to the Pocahontas and New River coal fields, obtain the best steam coals in the country at figures generally below one dollar a ton, while the railroads of the southwest pay from \$2.50 to \$3.00 a ton (or more) for a much less desirable article. If we contrast the cost of heat units, we find a still greater discrepancy. Thus for the New River coal, containing 14,000 B.t.u. at \$1.00 per ton, we have

$$\frac{14{,}000 \times 2{,}000}{1.00} = 28{,}000{,}000 \text{ B.t.u}$$

purchased for a dollar. Arkansas coal, containing about 11,000 heat units, costing \$2.70 a ton in Texas, gives us

$$\frac{11{,}000 \times 2{,}000}{2.70} = 8{,}150{,}000 \text{ B.t.u.}$$

for a dollar, a price 3½ times as high as in the previous case, and its effect upon the cost of transportation is felt accordingly. Nearly all railroads have more or less option in the matter of purchasing coal, and it then becomes a consideration of getting the most *heat* for the least money. In a lecture before the engineering students of Purdue University, in December, 1903, Mr. W. H. Bryan illustrated this point by a table which is partly reproduced below. This shows the cost of various fuels at St. Louis, the heat units contained in a pound, and the cost of evaporating 100 lbs. of water, which would be about equivalent to a movement of 50 ton-miles on the basis before assumed.

VALUE OF COAL AT ST. LOUIS.

Kind.	Cost, per ton.	B. t. u., per lb.	Cost of evaporating 100 lbs. of water.
Anthracite	\$6.75	14,000	31.08 cts.
Coke	4.50	12,500	24.87 "
Pocahontas	4.75	13,300	24.00 "
Big Muddy	2.50	12,200	14.60 "
Mt. Olive Lump	1.60	11,200	10.62 "
Common slack	.90	10,000	7.25 "

Such a comparison should always be made by every railroad company before making its contracts for fuel, but consideration must also be given to the fact that some kinds of fuel will not be satisfactory for high grades of service (passenger, for instance) unless the engines are designed especially for it. Thus, by building locomotives with grates of 80 or 90 sq. ft. of surface, the Reading was able to use anthracite culm, a fuel which had no value for locomotives as ordinarily constructed. Another case is that shown below, in which the figures are taken from some tests made on the Chicago & North-Western in 1900. Two kinds of Illinois coal were tried, which we will designate as A and B, costing $1.72½ and $1.57½, respectively. An ordinary eight-wheel engine, with narrow fire-box, and an Atlantic type, with wide grate, were used, the former hauling eight-ear trains, and the latter nine-car trains, the distance being 143 miles.

RESULTS OF COAL TESTS.

Kind of coal.	Type of engine.	No. of cars.	Cost Per ton.	Cost Per trip.
A	8-wheel	8	$1.72½	$9.68
B	8-wheel	8	1.57½	9.89
A	Atlantic	9	1.72½	10.83
B	Atlantic	9	1.57½	10.60

It was generally conceded that the "A" coal was the better—fully equal to the difference in cost, and the eight-wheel narrow fire-box engine showed greater economy per trip with this fuel. The wide fire-box engine, however, had so much grate that the poorer coal could be burned to advantage (perhaps with smaller draft and less cinder losses), and was even the most economical for the whole trip. This shows the importance of considering all the points at issue.

On large systems the various divisions must be supplied with coal from contiguous mines, if possible, and this causes a difference in price for different portions of

the road. In some cases it is pro-rated and charged out at a uniform figure throughout. On the Santa Fé a combination of these two methods was used. The coal used on the ten divisions of the original system was pro-rated, and for a certain month was charged out at $1.50 per ton, regardless of its actual cost or quality. For the same month the Albuquerque division was supplied with its fuel (a New Mexican lignite) at $1.16 per ton, and the Northern division (of Texas) was charged $2.48.

The changes in price in short lapses of time are often quite startling. Thus in two months the figure for New Mexican lignite fell from $1.51 to $1.16 per ton; on the Lake Shore in one year it rose from $1.63 to $2.10—nearly 30 per cent. increase. The use of fuel oil in California and Arizona has greatly reduced the expense of steam generation, although in order to gradually charge out the cost of the properties, the price of the oil has, in some cases, been maintained at quite a high figure; for instance, while actually costing about $1.50 a ton to produce (equivalent in heat to 1½ tons of coal, or nearly two tons of lignite) it was charged to locomotives at $4.00.

These variations show how extremely difficult it is to make intelligent comparisons of fuel cost on any unit basis, for different roads or different divisions of the same road, even without considering the physical characteristics (which will be taken up later), and also for the same division during different periods of time.

HAULING.

The prices just given are usually those paid for coal either at the mine, when adjacent to the railroad consuming it, or delivered on the line by some other railroad, at its nearest point to the mines; in either case, it must be hauled to the distributing points throughout the length of the road, and there is generally no charge made for this

service, such as an addition to the price of the coal at the mines to cover the expense of this haul. Company's property is ordinarily hauled without any specific charge being made for the same, but, nevertheless, it costs money to transport it, and in estimating upon the comparative value of different fuels, this should be remembered. It may not be clear just what is the proper charge to place upon such transportation, as it is possible to consider the problem in a variety of ways. Unless the quantities of fuel to be hauled constitute a large proportion of the traffic, it is clear that superintendence, maintenance of way and structures, station service and miscellaneous contingencies will only be imperceptibly increased, if at all, by such additional tonnage, and that engine service, train service and maintenance of equipment will be the only accounts which will be actually increased. That is, if such hauling was not done, charges first mentioned would still be as great, and would have to be pro-rated over the revenue ton mileage or train mileage. Cases occur, however, where such tonnage is a very large proportion of the total traffic, as for instance during a coal strike and water famine, which occurred together in the southwest, when the fuel and water hauled amounted to 60 per cent. of the total tonnage transported over a portion of the line. Under such circumstances the revenue freight would have to stand very large charges for superintendence, etc., if it were not pro-rated uniformly over all the traffic. The fairest method is probably to charge the full proportion of operating expenses to such freight based on a net ton-mile distribution, although it certainly does not increase the cost of operation (usually) by this amount. The actual sum is specified by the proper accounting officer, based on certain rules which have been laid down, and the operating expenses for the preceding month or year. Its value is likely to fall between ¼ and ½ cent per ton-mile, although even this is susceptible of different constructions. For instance, on a large system in the west, the

average cost of operation for March, 1903, was .41 cent per ton-mile net, while certain main line divisions ran .32 cent, and certain branches, where traffic was light and grades severe, 2.81 cents per ton-mile net. The principal coal-carrying branches cost about ½ cent per ton-mile, which, it seems, would in this case be the proper charge to add to the "mine cost" of the fuel. Thus every hundred miles that it was necessary to haul coal from that point of delivery to the chutes increased its cost 50 cents a ton, as a matter of actual fact.

HANDLING.

This constitutes another charge against locomotive fuel. It may be included in the stated cost, or it is sometimes charged to a separate account. In any event, it increases the cost to the locomotive by an amount depending entirely upon the methods in vogue. At a recent convention of the Association of Railway Superintendents of Bridges and Buildings, the various methods of handling coal were stated to cost approximately as follows:

METHOD OF HANDLING.

		Cost, cts. per ton.
1.	Shoveling from railroad cars to tenders	25
2.	Shoveling from cars to high platforms and again shoveled on to tenders	25 to 50
3.	Crane and bucket from storage platform	35
4.	Shoveling from cars into bins from elevated trestle.	10
5.	Dumping from railroad car directly into bins	1½ to 3
6.	Hauling railroad cars by cable up steep incline and dumping directly into bins	3
7.	Dumping from railroad cars into pit and elevating by conveyors	3
8.	The same as above, but elevating by air hoist	5 to 10
9.	Locomotive crane working from stock pile to bins or to tenders	1¾
10.	Dumping through trestle to platform and tramming and dumping into tenders	10 to 15
11.	Dumping into pit in track and elevating skip by switch rope by engine taking coal	5 to 10

These figures seem very confusing in a way, for, it may be argued, if coal can be handled for 3 cents a ton, who would think of paying 25 cents or more. But this statement does not tell the whole tale. It is apparent at first sight that the cheaper methods of handling require a more costly plant and a correspondingly greater investment. Now, in railroad accounts interest on the original cost of a plant is not usually included in the operating expenses, as it is covered by bond issues bearing stated amounts of interest, constituting "fixed charges," or by dividends on the stock. Nevertheless, it is an expense, as, perhaps, bonds must be sold that bear 4 or 5 per cent. interest to pay for the improved facilities.

Depreciation likewise is not charged, except in a way by replacement funds, but it exists and must be accounted for. If now we assume interest on investment at 5 per cent. and depreciation at the same, we would not be justified, from a financial standpoint, in erecting a modern coaling station, unless sufficient fuel were handled every year at such station, so that the saving in cost of operating the plant would at least be 10 per cent. of the increased investment. There are many points on a railroad where a few engines only need to be coaled, and it is this very consideration that often accounts for antiquated and expensively operated (on the ton basis) coaling plants on important roads. Then, too, it is sometimes impossible to obtain the authority and funds to make much-needed improvements at even important points, where large numbers of engines are coaled every day, and thus the cost of fuel as delivered to the engines is much greater than would appear at first sight.

LOSS.

But there is still another increase which is often made in the fuel accounts, and this is due to "loss or shrinkage" from various causes. At times the improper

handling of accounts causes a shortage in the fuel account when the stock is inventoried, and in order to square up this account, either short weight is delivered to the engines, or the price is increased, to take up the deficit. The result is the same, in either case—you cannot cheat the fire-box, and if 1,900 lbs. are placed on the tender *for a ton,* you will still only obtain steam due to 1,900 lbs. of coal. It seems as if the fairest way was simply to raise the charging-out price sufficiently to close the deficit in a reasonable time, as this does not interfere with the enginemen's coal records. The writer remembers one case where the engineers and firemen were being interviewed regarding the increase in coal consumption per ton-mile, and finally one of the men stated that at a certain coal chute but 1,800 lbs. were being served for a ton. This was found to be true, and the investigation fell flat, as far as the men were concerned. On another road a large shortage had occurred in the fuel accounts during a previous administration, and for several years short weight tons were served all over the road, until the shortage was extinguished. This, perhaps, prevented making difficult explanations, but the result was the same—and the engines stood the "brunt of the battle," as usual.

It is quite common for large piles of soft coal to catch fire spontaneously, and many tons will be destroyed, besides the expense of removing the burning and charred coal, which is about the only way that such a fire can be conquered. It is a good plan to separate large piles by masonry walls, and to avoid stacking it much over 8 ft. in height. It has also been suggested that pipes be stood upright in the coal piles and at intervals thermometers be dropped to the bottom by cords, and then withdrawn, in order to see if a dangerous degree of heat has been generated.

When such losses occur, unless there is insurance available, the natural course to follow is either to raise the charging price (which is decidedly preferable) or to

give short weight for a term, thereby invalidating the enginemen's fuel records, as compared with previous months, or with other divisions not affected by the loss.

STORAGE.

In order to protect themselves against traffic interruptions due to coal strikes, etc., many railroads store large quantities of coal at some point or points, more or less convenient. While there is seldom, if ever, any charge made for storage, there is expense attendant upon the same. Facilities of some kind are needed, if nothing more than a track or trestle, and these mean an original outlay. In some cases, as the New York Central's storage plant at Syracuse, machinery is installed, involving quite an expense. Then the extra handling for unloading and loading again for shipment to the chutes must not be forgotten. Cases have occurred where the reloading was done by steam shovel, and while the cost of handling was small, there was a great quantity of stones and natural soil picked up by the dipper, which finally found its way into the tenders, causing failures for lack of steam and general complaints, both by despatchers and enginemen. Again, many coals, when stored upon open ground, are very unfavorably affected by the weather, and depreciate greatly in heating value. Much of the lump goes to slack, and if needed for passenger service, coke-forks must be used, sorting out the lump for the most important trains, and allowing the freights and switchers to struggle along with the fine stuff. This means a double loss—the extra labor involved in preparing and loading the coal, and the poor steam-making qualities of the refuse. But when a shortage in fuel occurs everything must be done to keep trains moving, even if an increase in expenses be caused thereby. Such cases are by no means rare, as the writer has passed through a number of such experiences.

When oil is used as fuel many of these troubles are obviated, but others crop up. All shipments of oil contain more or less water—sometimes *more than less.* The continual filling of storage tanks from tank cars, and the accumulation of considerable quantities of water therein at times result in undue quantities of water being found in the tender oil tank. Cases have occurred where the burner would not start, and upon investigation it was found that water was flowing to it instead of oil. All tender oil tanks have drain cocks at the bottom for the purpose of removing this water, but it is bought and paid for as oil and increases the cost of fuel accordingly. Tank cars are often found to contain quite a depth of sand or deposit at the bottom, and as the bills are rendered on the basis of measured capacity (or loaded weight less stenciled light weight) there occurs a shortage which must be made up in some such manner as previously indicated.

We see from this category of possible expenses that it is really quite a difficult matter to determine the *exact cost* of fuel delivered upon the tenders, and that the billed price of the coal conveys but little idea of the real cost. If we desire to know the number of heat units produced in the fire-box for every dollar spent upon the fuel, which involves definite information regarding the quality and composition, we have a task infinitely more difficult, unless actual tests and analyses are conducted with samples from each tender load, and yet the largest item of operating expense is dependent upon just this specific combination of cost and quality, and every official, from the general manager to the road foreman of engines, is constantly studying and answering questions regarding a variation of a fraction of a pound of fuel or a cent in expenses per 100 ton-miles of movement!

FIRING.

When the coal has been placed upon the tender the uncertainty regarding its value for generating steam has by no means come to an end. It is now used for two purposes: for getting up steam in the house and for hauling trains on the road. The first proceeding is unremunerative and very uncertain, depending largely upon how long and where the engine stands after the fire is lighted. Ordinarily it should be a very simple matter to say how many pounds of coal would be required to bring the weight of water in the boiler and the material of the boiler itself up to a temperature corresponding to the steam pressure carried. In some tests made upon the Santa Fé, locomotives of quite a large size consumed from 1,200 to 1,600 lbs, in firing-up, the time occupied being from four to six hours, but how often does an engine go on duty as soon as fired-up to the proper pressure? What a common sight if we go to a large roundhouse on a winter's night, to find 10 or 20 locomotives standing outside, perhaps in a storm, their gages all near the working pressure, and nearly one-half of them blowing off through the safety valves! In his anxiety not to delay trains, the despatcher has perhaps ordered all the locomotives available, and while the trains for which they are intended may not all be in for five or six hours, in the meantime fuel is burnt without producing any useful work. The amount of steam escaping through a 2½-in. safety-valve every minute that it is relieving pressure represents the evaporation caused by burning 15 lbs. of coal—sufficient to haul 100 tons for one mile on a road of easy grades, and it is therefore not to be wondered at that enginemen who are interested in their coal record ask for allowances to their credit when engines are compelled to stand under steam, and the fuel used is reckoned against their ton-mileage. Even when not blowing off, radiation alone will require from 25 to 50 lbs. an hour. As soon as the loco-

motive starts on its trip the fireman's efficiency becomes a factor in the problem, and a very important one. If he fills the air with clouds of black smoke; if he throws in large lumps without breaking them, or fires six or eight scoopfuls at a time instead of two or three; if he allows the engine to blow off; if he fires aimlessly, not observing where the coal is needed, or carries a very heavy fire; if he neglects the proper use of dampers or disregards the actions of the engineer in handling the engine, it cannot be expected that anything like the full value of the fuel will be obtained and a great deal more coal will be used in doing a certain amount of work than with a man who fires intelligently and practices none of the bad methods just enumerated.

There is practically no limit to the various books and articles of instruction regarding the proper firing of locomotives, and while it is not in the province of this work to go into the details of making a good fireman, it is important to explain the great cost to any railroad of careless or incompetent men.

In order to stimulate a healthy rivalry, many roads keep and post up individual performance sheets, which show each month the amount of fuel per ton-mile which the several men have used in different classes of work on the division. Unless these be properly grouped for comparison, they are worse than useless, and discourage the men instead of stimulating them to give better service, and this is the difficult part of the problem. If one man has caught more fast freights or stock runs than his competitors during the month, he cannot be expected to show as low a fuel rate as the others, and if it be insisted that he can, he will feel the injustice of the charge and lose interest in the proceeding. Where a number of men have definite runs that are practically similar, such comparisons may be drawn with evident advantage to the industrious and willing employe and the company, as for

instance, in passenger trains, where two crews run alternate days; if one crew has more lost time from another division to make up, they will probably obtain a poorer mark, but will be able to explain when desired to do so. Perhaps the most satisfactory method is to group the men each month, according to their service, as nearly as possible, even if only four or five appear in a group, or sometimes only two. If after four or five months are compared it is found that certain men are continually below (or rather above in amount of fuel used) the average of the group in which they are placed, it is a good indication that they are doing poorer work than the average of their competitors. It may be due to the grouping, or to a large number of fast trains, as indicated above, but if the arrangement of the men be carefully performed, the conditions should average themselves in the course of a few months so as to demonstrate who are the careless parties. If large groups of figures are published regularly, they do not often appeal to the men as forcibly as some mark, suggestive of a better or poorer performance than the average of the group; besides, the men will keep a tally of their coal tickets, and attempt to check up the amounts stated in the bulletins, with the result frequently of a disagreement in the figures. Then confidence is lost in the company's statistics, and complaints are frequent and emphatic that the statements "are not worth a ——," and that it is not just to judge them by the monthly sheets. On the other hand, if it is simply shown that John Doe is always below the average of his group, he either must have some good reason (which can and should be investigated) or the fault lies with himself, until he is able to demonstrate otherwise. It is just such difficulties as above enumerated that have caused the abandonment of the coal premium system on most roads, as it was extremely hard, if not impossible, to pay justly for saving in fuel.

RUNNING.

We have given considerable space to the duties of the fireman in economizing fuel, and the methods of recording the same, but it must be remembered that the engineman is the responsible party on the engine, and that he has much to do with the proper use of the coal, and is even more interested (or should be) than the fireman. As a graduate from the "school of the scoop" he should instruct his firemen, where necessary, and endeavor to cultivate in him an interest in his work; he should also assist him to make a record by working his engine in the shortest cut-off possible consistent with the work he has to do, using a liberal throttle opening, taking the full card time between stations, uniformly distributed (unless making up lost time), operating the injector as evenly as possible throughout the trip, and keeping his fireman posted beforehand of his intended movements in the operation of the locomotive.

The road foreman must see that the engineman and fireman are working in harmony, and that they fully understand the importance and methods of economy, without interfering with the proper movement of trains, or the observance of orders.

What was said about the fuel records of firemen applies equally to the enginemen; in fact, where they run together they are grouped side by side in the statement. Occasionally, however, it is necessary to make out separate statements for enginemen and firemen, but the same form and arrangement will answer.

These matters have been studied at some length on account of their importance to the cost of fuel, and for the purpose of demonstrating the still further difficulty of expecting exact figures for this item. If all men had the same intelligence, skill and willingness, this factor could be overlooked, but the "personal equation" is what

really constitutes individuality, and nowhere in locomotive operation is it more a matter of financial interest than on the locomotive footboard. As supervision of the actions of the engine crew in detail is impossible, the variation in results can be readily appreciated.

DESIGN.

The detail proportions and the arrangements of the locomotive have much to do with the fuel consumption. In fact, some kinds of coal require special appliances for burning them properly. Thus, in order to burn anthracite culm, a fuel which could be obtained on the line of the Lackawanna Railroad for a very small price, it was necessary to design boilers with enormous grate surface, and also to use grate bars specially suited to the fuel. This has been done successfully, but could not have been attempted without these modifications. The Philadelphia & Reading at one time burned soft coal, and when it desired to return to anthracite it was necessary to change the back end of the boilers; of course, hard coal could have been burned upon the smaller grate, but not in sufficient quantities to generate the desired amount of steam. These cases are cited merely to show the importance of design to fuel combustion.

The effects of some special features are well known —of others they are more or less problematical. Compounding, when the engines are in good condition, may be expected to diminish the coal consumption 10 or 20 per cent. below simple engines, for the same amount of work; if there are leaks and blows (and in some cases these are much more prevalent and difficult to repair than in simple engines) the saving may disappear or become negative; then it has sometimes been found that where the division consists of a long gradient in one direction, the steam used by a compound in order to cause it to run swiftly down hill, may very nearly equal the economy of

the up-hill trip, thereby leaving a very small balance in its favor. The most advantageous line for such an engine is evidently one where steam can be used liberally for the whole running distance; that is, a nearly level stretch of track.

If the engine be equipped with a superheater we may expect economies which compare favorably with the compound. Approximately, we should obtain 5 or 6 per cent. fuel economy for every 110 deg. of superheat, so that we need not look for as good a performance in an ordinary boiler. Of course, in computing or estimating the consumption of fuel for a given work, these features can be allowed for, but in any case they should not be overlooked.

Large grates and piston valves also tend toward economy, and while it is frequently stated that they will produce 10 per cent., if judiciously applied, it is not so easy to compute this definitely as in the cases previously quoted. These points are mentioned to show the effect of design upon the economy of fuel, and as most railroads have many of these varieties running over the same divisions, a close correspondence between them in coal consumption cannot be expected. They all exert an influence upon this most important question, but just how far can seldom, if ever, be exactly stated. Minor details, such as the size of port, length of stroke, boiler covering, etc., all contribute toward economy or extravagance, according to the skill of the designer and the service to which they are applied, but the exact amount of their influence will perhaps never be known.

CONDITION.

But if the design is important the maintenance is even more so. As has been hinted in speaking of compounds, inattention in the roundhouse or shop will easily destroy the saving produced, or that should be produced,

by the special feature, to obtain which an additional expense has been incurred. Blowing packing or a leak in the boiler will offset a good many per cent. of saving, and when we see a locomotive surrounded by a cloud of steam we know that such steam has not performed its intended work, otherwise it would come only from the stack. In a recent trip over one of our transcontinental lines, on some divisions it was a rare occurrence to find a boiler that was not leaking; this may be due to the nature of the water or fuel used, but, nevertheless, the waste existed.

Cut valve seats, allowing steam to blow through to the exhaust; injectors that do not shut off; cylinder cocks that do not seat properly are all sources of waste that are caused by imperfect maintenance. Improper adjustment of the draft diaphragms, affecting the steaming, or an excessively small nozzle, whereby large percentages of unburned fuel pass through the stack are an evidence of insufficient care in the roundhouse. Neglected boiler washing, allowing scale and sediment to accumulate on the heating surfaces, besides injuring the metal, causes a loss of heat by the non-conducting qualities of the deposit. In some tests made by the Illinois Central, a thoroughly cleaned boiler showed 13 per cent. increase in steam-making power (see *Railroad Gazette,* Jan. 27, 1899) over what it had done previous to removing and cleaning the flues. Of course, we cannot obtain such a difference by merely washing out, but this shows the necessity of watchfulness along this line.

The care of the jacket is also important, as if engines are allowed to run with portions of the jacket removed, the radiation from the uncovered surface causes an additional loss of from one to two British thermal units per sqaure foot per hour per degree difference in temperatures between the inside and outside of the boiler. These all show the importance of maintaining locomotives in prime condition, if economy is to be obtained and the

relative importance of the different processes can be understood from the foregoing.

With all these variables which have been enumerated, affecting the quantity and value of the fuel, it is not difficult to understand the impossibility of prognosticating or even obtaining the actual amounts used in moving trains, both in pounds and dollars for any given case or for a group of engines. However, the effects of grade, speed, load, etc., are so very prominent that they outweigh most of the variables above noted—in fact, these very uncertainties may actually balance each other, some, but not all, being present in nearly every locomotive, and the result being a general reduction in the work performed per pound of coal, which many be covered in the assumed unit of performance. Besides, these physical characteristics can be properly considered in the ratio of their effects—that is, if such a grade, etc., requires so much fuel —another one will require a definite proportion of the first, practically eliminating consideration of these variables.

USEFUL WORK.

The items heretofore considered have been mostly connected with the waste of fuel, and were introduced to impress upon the reader the many difficulties to be overcome in order to observe strict economy. While these all have a great influence upon the cost of the service, it is a fact that only the proper amount of fuel is consumed in doing the work of the train that is required by the laws of nature—the balance is burned in an attempt to make up for leaks and other deficiencies in maintenance or operation of the engine; that is to say, that a given amount of work requires a definite quantity of heat, and no more can be utilized in performing the work, but is wasted in one or more of the various ways enumerated. It is therefore perfectly logical to determine the amount of fuel needed for doing useful work, and if the engine

is in poor condition or improperly treated, an allowance should be made in estimating the total coal consumption. What this should be it is generally impossible to state, as there is no way of accurately estimating the effect of such circumstances. As tests are made under ordinary working conditions, we can assume that the values so obtained will cover a number of defects which generally have to be contended with, but leaks and other severe drains upon the boiler should certainly not be included.

All work performed is the product of force and speed, and so the work done by a locomotive is represented by the drawbar pull or the tractive force, and the speed at which this force is maintained. If now we can determine the quantity of fuel required for any and all combinations of speed and pull within the capacity of the engine, we can also, by knowing the resistance offered by grades, curves, etc., find out the amount of coal needed on such grades, etc., in order to take the train at the required speed. From a study of some tests made by the author a few years ago, it has been found possible to elaborate a diagram for any particular locomotive whose general dimensions are known, which will give at once the fuel consumption per mile or per hour, the diagram being based upon theoretical as well as practical considerations, and giving values, it is believed, agreeing closely with actual conditions.

The construction of the diagram and the method of using it can, perhaps, be made most clear, by assuming a locomotive of certain proportions, and developing the study for this engine. We will consider a consolidation locomotive or 2-8-0 type having the following general dimensions:

Diameter of cylinders	21 ins.
Stroke of pistons	32 "
Diameter of drivers	56 "
Boiler pressure	200 lbs.
Grate area	40 sq. ft.
Heating surface	3,200 "
Weight of engine and tender	150 tons

The theoretical tractive force of such a locomotive will be

$$T.T.F. = \frac{P\ d^2\ s}{D} \quad \ldots\ldots\ldots\ldots\ (2)$$

where P = Boiler pressure in pounds per sq. in.
d = Diameter of cylinder in inches.
s = Stroke of piston in inches.
D = Diameter of drivers in inches.

When we allow for drop in steam pressure and internal resistance, we find that the available tractive force at circumference of the drivers is only .8 of the theoretical tractive force, or

$$A.T.F. = \frac{.8\ P\ d^2\ s}{D} \quad \ldots\ldots\ldots\ (3)$$

for simple engines, when working at slow speeds with the reverse lever in the corner notch.

For the engine under consideration we therefore find as follows:

$$T.T.F. = \frac{200 \times 441 \times 32}{56} = 50{,}000 \text{ lbs. approx.}$$

$$A.T.F. = .8 \times 50{,}000 = 40{,}000 \text{ lbs. approx.}$$

As the speed of the locomotive increases, however, beyond the point where the boiler can supply the complete volume of the cylinders at each stroke, an earlier cut-off must be used, and it is necessary to determine the effect of such a change. In order that this may occur at the maximum possible speed, the boiler must be worked to its full capacity, which is limited by its ability to burn fuel. From various tests it seems as if this limit might be considered as stated below, the quantities being expressed in pounds of coal per square foot of grate area per hour:

Bituminous coal	200 lbs.
Anthracite, large sizes	100 "
Anthracite, small sizes	60 "

We will assume that our engine is burning Pennsylvania or Virginia semi-bituminous coal, therefore the maximum combustion will be $40 \times 200 = 8{,}000$ lbs. coal per hour. We admit that this is a large amount to be handled by one man for any great length of time, but there is no doubt that it could be burnt if supplied. In order to determine the quantity of steam generated by this amount of fuel in the boiler which we have assumed, Fig. 1 is introduced. This has been compiled from various sources of information, and it is thought fairly represents the average practice in this country. In this figure the ordinates give the maximum evaporation in pounds of water from and at 212 deg. Fahr. per square foot of heating surface per hour that can be expected under ordinary-conditions, as stated above, the abscissae denoting the ratio of heating surface to grate area. For the engine in question this will be

$$\frac{3{,}200}{40} = 80,$$

and for semi-bituminous coal, curve "C," we find that with a ratio of 80, fifteen pounds of water from and at 212 deg. may be evaporated per hour from each square foot of heating surface, or for the boiler as a whole,

$$3{,}200 \times 15 = 48{,}000 \text{ lbs. per hour.}$$

The factor of evaporation from ordinary temperatures of feed water will be about 1.2, so that we shall have at boiler pressure

$$\frac{48{,}000}{1.2} = 40{,}000 \text{ lbs. per hour.}$$

The steam will be somewhat reduced in pressure at the cut-off point, however, and the table here given indicates the probable relation of this pressure to the boiler pressure, when the reverse lever is in the corner notch, and the throttle wide open.

Ratio of Cut-off Pressure to Boiler Pressure.

Revolutions per min.	Starting.	50.	100.	150.	200.
Long ports	0.98	0.96	0.88	0.83	0.78
Short ports	.98	.92	.85	.77	.72
Medium ports	.98	.94	.86	.80	.75

By long ports is meant those in which the length of port in inches divided by the area of the cylinder in square inches is, approximately, .12, and by short ports, where this ratio is about .05. If we assume .90 for the ratio in the case in hand, we shall have

$$200 \times .90 = 180 \text{ lbs. at cut-off,}$$

which steam will weigh .432 lb. per cubic foot. The volume of a cylinder 21 in. in diameter and 32 in. long is 6.4 cu. ft., or for one revolution four times this amount, or 25.6 cu. ft. No allowance is made for clearance, as the cut-off, with lever in the corner, is usually about 90 or 92 per cent. of the stroke. For each revolution, then, the steam consumption will be

$$25.6 \times .432 = 11.06 \text{ lbs.}$$

and

$$\frac{40{,}000}{60 \times 11.06} = 60 \text{ revolutions per minute}$$

as the maximum speed at which the boiler will furnish steam at full stroke. The speeds in miles per hour corresponding to the revolutions per minute for a 56-in. wheel are as follows:

5	10	15	20	25	30	35	40	miles per hour.
30	60	90	120	150	180	210	240	revs. per min.

Therefore it is plain, that above 10 miles an hour the cut-off must be reduced, diminishing the available tractive force of the engine. A study of the variation in tractive force due to speed indicates that the method explained below gives a close approximation to actual results.

In Fig. 2 the ordinates represent the tractive force in pounds, and the abscissae the speed in miles per hour. As the maximum speed at full stroke was found to be 60

r.p.m., or 10 miles an hour, we find the intersection of this speed with the theoretical tractive force at "A." We therefore construct an equilateral hyperbola through this point; that is, a curve, the product of whose ordinates will always have the same value, viz.: $50{,}000 \times 10 = 500{,}000$. As we have seen, the available tractive force, however, cannot exceed 40,000 lbs. By drawing from the point "B" a tangent to the hyperbola, we then have a locus consisting of a straight line and a curve, and this locus gives us the maximum available tractive force (at circumference of the drivers) for which the boiler will supply the cylinders at any speed. But to do this, we must burn 8,000 lbs. of coal an hour, so that the locus BC also gives the combinations of speed and available tractive force which may be obtained by the combustion of 8,000 lbs. of coal an hour..

The rate of combustion per square foot of heating surface per hour is $\frac{8{,}000}{3{,}200} = 2.5$, and from Fig. 3 (curve C) we should expect 6 lbs. of water per pound of coal from and at 212 deg., or a total steam production of $8{,}000 \times 6 = 48{,}000$ lbs., which is the same as our first figure. If the rate of combustion be reduced, however, there will be more steam generated per pound of coal, as indicated by Fig. 3. For instance, if three-quarters the amount be consumed, or 6,000 lbs., the rate of combustion will be $\frac{6{,}000}{3{,}200} = 1.87$ lbs. per sq. ft. of heating surface, and from Fig. 3 the evaporation will be about 7 or $7 \times 1.87 = 13.09$ lbs. of water per sq. ft. of heating surface per hour, instead of 15 lbs. as before. This would supply the cylinders at full stroke for 15:13.09: :10:8.7 miles an hour. From this, as a starting point, we construct a new hyperbola and tangent as before, which locus gives the combinations of speed and tractive force for 6,000 lbs. of coal an hour. In the figure the loci have been drawn for each thousand pounds per hour from 1,000 to 8,000.

If now we divide the quantities per hour by the speed we obtain the fuel consumption per mile, and this is shown by the dotted lines. Thus, with a tractive force of 20,000 lbs. and a speed of 15 miles an hour, we should expect an hourly consumption of 3,000 lbs., or 200 lbs. per mile. With a force of 25,000 lbs. and a speed of 20 miles an hour we should use 400 lbs. per mile, or 8,000 lbs. per hour, and as this is our limit of combustion, if we wished more tractive force, we should be compelled to

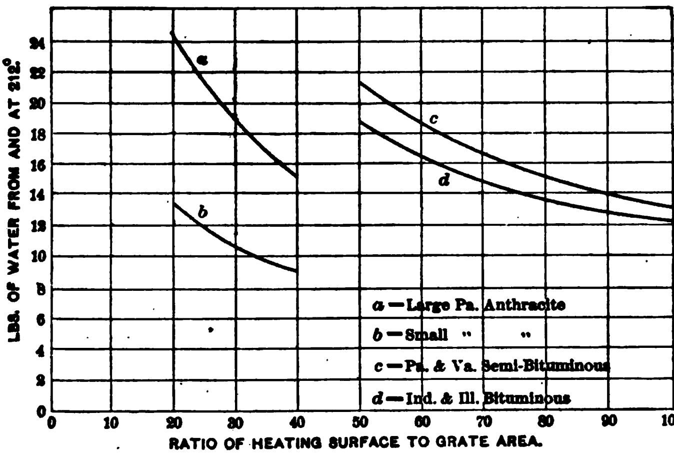


FIG. 1—MAXIMUM EVAPORATION PER SQUARE FOOT OF HEATING SURFACE PER HOUR.

reduce the speed. For instance, if we needed 30,000 lbs., the speed would fall to 17 miles an hour, and at that velocity we should just be able to maintain the 200 lbs. pressure in the boiler. If we wished to increase our speed to 30 miles an hour, the train load would have to be reduced so that a tractive force of 17,000 only would be needed. The line BC therefore gives the limiting conditions of operation, and, of course, the 40,000-lb. tractive force line limits the pull below 10 miles an hour.

If the engine were burning fuel oil, our calculations

would be somewhat different. As a grate is not used, but merely an oil injector, we must figure upon the heating surface only. It has been found possible to burn oil at the rate of nearly 1½ lbs. per sq. ft. of heating surface per hour, and to obtain an evaporation of 12 or 13 lbs. of

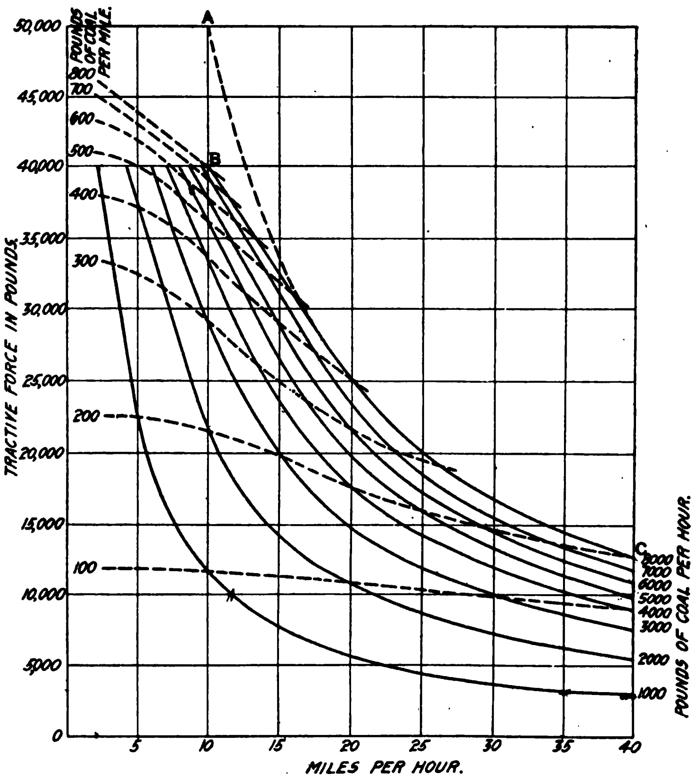


FIG. 2—COAL CONSUMPTION OF A SIMPLE LOCOMOTIVE.

water per pound of oil from and at 212 deg. It is probable that this rate can be exceeded, but just how much we do not know. This gives us 18 lbs. of water per sq. ft. of heating surface evaporated per hour from and at 212 deg., or a total steam generation of 3,200 × 18 = 57,600

lbs. Dividing by the factor of evaporation 1.2, we obtain 48,000 lbs. per hour, and also $48,000 \div (60 \times 11.06) = 72$ r.p.m., or 12 miles an hour for the maximum speed at which steam may follow full stroke. Fig. 4 has been constructed in a manner similar to Fig. 2, the product of the co-ordinates of the curve BC below the point of tangency equaling $50,000 \times 12 = 600,000$. The curves representing the consumption per mile and per hour are found as before explained, the maximum being assumed at $3,200 \times 1\frac{1}{2} = 4,800$ lbs. per hour. The increase in

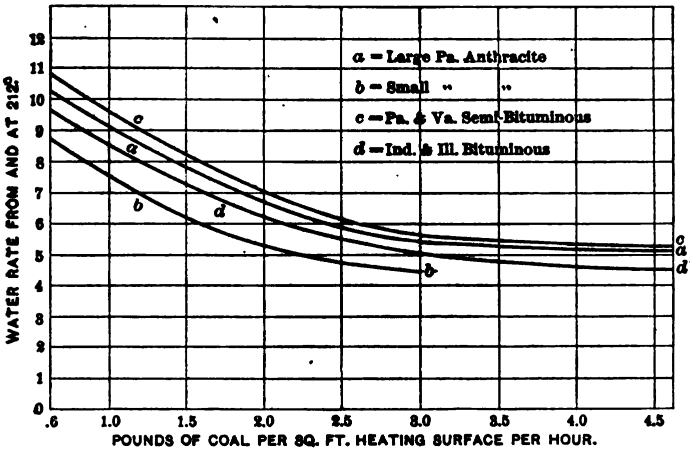


FIG. 3—EVAPORATIVE VALUE OF COALS.

speed for a given tractive force or vice versa, as compared with coal (Fig. 2), is quite interesting, and is well known from practical observation, where oil burners are used in the same territory as coal-burning locomotives.

For example, from Fig. 2 we found that with a tractive force of 25,000 lbs. the maximum speed that could be expected would be 20 miles an hour. In Fig. 4, however, with this tractive force, a speed of 24 miles an hour could be maintained, or at 20 miles an hour, a tractive force of 29,500 lbs. could be exerted. Again, with a pull

of 30,000 lbs. we could attain a speed of 19½ miles an hour instead of 17, as before, and even better can sometimes be done, possibly by increasing the rate of oil fed and burned. The high rate of combustion and the great heat concentrated upon the fire-box sheets in the imme-

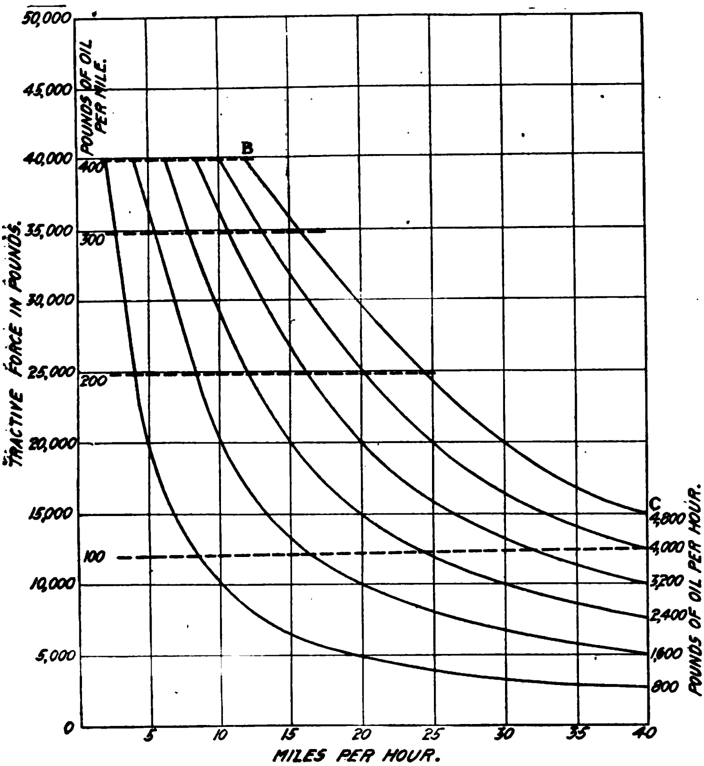


FIG. 4—OIL CONSUMPTION OF A SIMPLE LOCOMOTIVE.

diate vicinity of the arch are very destructive, and boiler repairs are frequent and costly, but for transportation purposes oil is an ideal fuel—there are no ashes to be removed; if properly handled, smoke is unknown, except when sanding the flues, and the labor of placing the fuel upon the tender is extremely small. The weight to be

carried is also much less, as will be seen from the diagram; when working at its maximum capacity, 4,800 lbs. of oil will do more work than 8,000 lbs. of coal. This is because at the high rate of combustion much of the coal is carried unburnt up the stack, whereas in oil burning, if

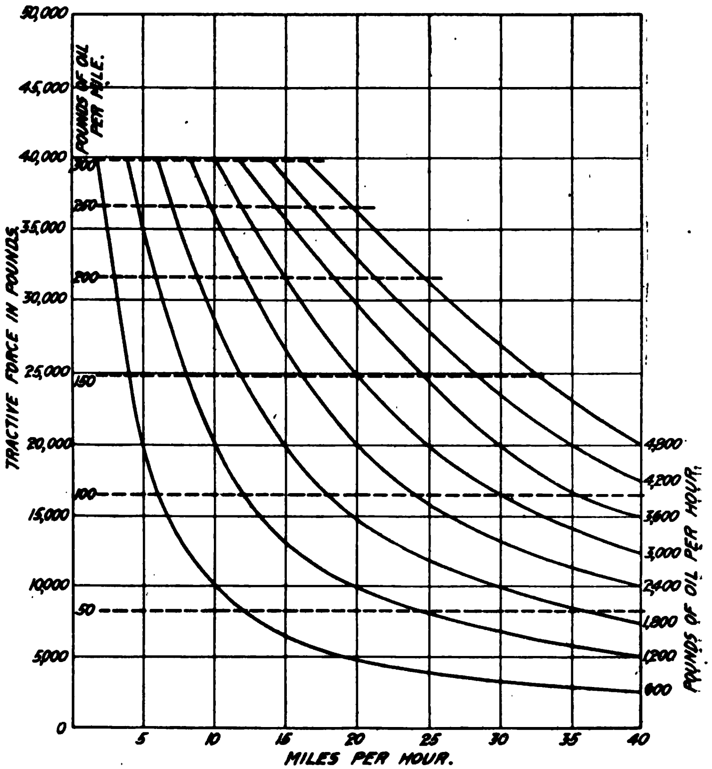


FIG. 5—OIL CONSUMPTION OF A COMPOUND LOCOMOTIVE.

the fireman be alert, there is practically no such loss. In the case of coal it cannot be prevented, but with oil it is a question of careful manipulation of the supply valves. As the rate of combustion diminishes, the loss of coal becomes less. Thus with a tractive effort of 20,000 lbs.

and a speed of 25 miles an hour, we would burn (or use) 8,000 lbs. of coal and only 4,000 lbs. of oil, or one-half as much. At 15 miles an hour, however, and the same tractive force we would use 3,000 lbs. of coal and 2,400 lbs. of oil an hour, four-fifths as much, due to the greater

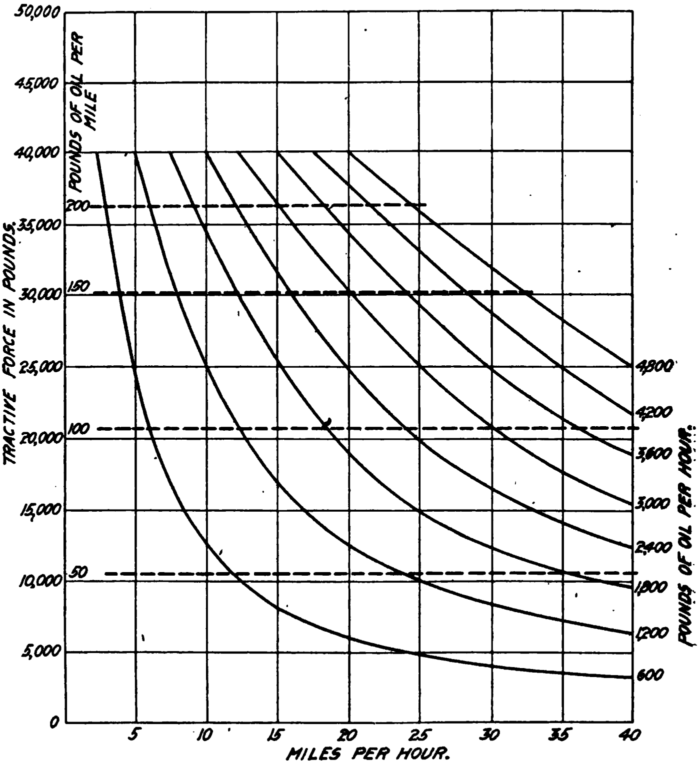


FIG. 6—OIL CONSUMPTION OF A COMPOUND LOCOMOTIVE WITH SUPERHEATER.

evaporative efficiency of coal at low rates of combustion than at high rates.

Suppose now that we compound our oil burner, and instead of simple cylinders 21 in. × 32 in., we use two high-pressure 18 in. × 32 in., and two low-pressure cylin-

ders 26 in. × 32 in. The volume of one high-pressure cylinder will be 4.7 cu. ft., or 18.8 for one complete revolution of four strokes. Multiplying as before, by the density, we obtain 18.8 × .432 = 8.12 lbs. per revolution, and with 48,000 lbs. of steam generated per hour we shall have 48,000 ÷ (60 × 8.12) = 98 r.p.m., say 16 miles per hour. The fuel consumption curves for this case are shown in Fig. 5, and we notice about 33 per cent. increase in the work per unit of fuel. This, of course, considers the engine maintained in good condition, and doing positive work; if running down hill, there will be no saving—sometimes a waste, as already explained. In any event, if the throttle be closed for half the time, then we could not expect as great economy for the whole distance, as the consumption down hill (for radiation, braking, etc.), will be equal to, if not greater than, that in the simple engine.

The lines showing the pounds of fuel oil used per mile are straight, as we do not have the cinder losses under high rates of combustion. But we may go further and introduce superheating in connection with our compound oil burner. This, with the same amount of "water" heating surface, will cause an increase in volume of steam supplied to the cylinders at the same pressure, and in proportions as indicated in the following table, depending upon the temperature at which the steam reaches the cylinders:

Ratio of Volumes of Superheated to Saturated Steam with Equal Fuel Consumptions.

Pressures........	175 lbs.	200 lbs.	225 lbs.
Temperature.		Ratio of Volumes.	
400	1.02	1.01	1.00
450	1.06	1.04	1.03
500	1.10	1.08	1.06
550	1.13	1.11	1.10
600	1.16	1.14	1.14
650	1.19	1.18	1.17
700	1.22	1.21	1.20
750	1.25	1.24	1.23
800	1.28	1.27	1.26

If we obtain 200-lb. steam at 760 deg. Fahr. we shall have an increase of 25 per cent., and instead of 16 miles an hour we can run $20 = 16 \times 1.25$ before exceeding the capacity of the boiler. Of course, this all depends upon actually being able to heat the steam to this temperature, and not merely upon the fact that a superheater has been placed on the engine. Fig. 6 gives a set of curves for this combination, and it is seen that the output of the locomotive has apparently been doubled when compared with the simple coal burner. Thus we find that the maximum speeds for various tractive forces stand as below:

Tractive force, lbs.	Maximum speed, per hr. Simple coal.	Comp. super. oil.
40,000	10 miles.	20 miles.
35,000	13 "	26 "
30,000	17 "	32½ "
25,000	20 "	40 "

Comparing the weight of fuel used for similar speeds and pulls, we see a great difference also. Thus, for 40,000 lbs. tractive force, at 10 miles an hour, we should use 800 lbs. of coal per mile, but only about 250 lbs. of oil. However, at the same speed and with a pull of 12,000 lbs., the quantities would be 100 lbs. of coal and about 55 lbs. of oil per mile. It must be remembered that these conditions are exceptional, yet they are no doubt possible, if the compound and superheating features are well designed and maintained. These points are of great interest, but they are merely preliminary to computing the consumption of fuel under different physical and operating conditions. It is necessary, however, to first obtain a clear conception of the construction and meaning of the curves, and for this reason we have gone into the matter at some length.

The tractive force enables the locomotive to overcome the resistance of trains, and it is necessary to determine the resistance or resistances due to the conditions

which have to be met, such as speed, grade, curvature, acceleration and loading, as well as weather and temperature variations. The formula which we prefer for "speed resistance" is that advanced by the *Engineering News* some years ago, and which is

$$R = 2 + \frac{V}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where $R =$ resistance in pounds per ton (2,000 lbs.).
$V =$ Velocity in miles per hour.

Below 12 miles an hour, formula (4) gives values that are generally too low, and therefore it is not applicable below that speed. At starting, the resistances are usually great, and are often taken at about 16 lbs. per ton. It is probable that at low speeds the resistance is about as follows:

Speed, miles, per hour.	Resistance in lbs. per ton.	Speed, miles. per hour.	Resistance in lbs. per ton.
0	16	6	5
1	11	7	5⅛
2	8	8	5¼
3	6½	9	5⅜
4	5½	10	5½
5	5		

However, the make-up of the train enters very largely into the proposition, and equation (4) takes no cognizance of such variations. It is well known that empty trains pull harder, for equal weights, than loaded trains, and we must allow for this circumstance. We can do this by using a formula that takes into account both the weight of the train and the number of cars. Thus, if we let

$T =$ weight of train in tons (of 2,000 lbs.);
$C =$ number of cars in train;
$f =$ a coefficient, depending upon the speed, and which may be taken equal to $3.5 + \frac{V - 12}{4}$, for speeds over 12 miles an hour;

we can express the total resistance of the train in pounds, on a level tangent, and at the tender draw-bar as equal to

$$f\,T + 50\,C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The values of f given below may be inserted in the formula:

Speed = V........	5	10	15	20	25	30	35	40
Coef. = f.........	3.00	3.50	4.25	5.50	6.75	8.00	9.25	10.50

When we study these values in connection with fuel consumption, we will discover the effects of loading upon coal economy.

The effect of a grade is to increase the resistance by an absolute amount, regardless of speed or loading, and this amount depends only upon the weight of train and the rate of gradient. If we let

M = rise in feet per mile;

N = per cent. of grade, we have

$$R = .38\,M = 20\,N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

R, as before, being the resistance in pounds per ton.

On curves, we may take the resistance as .7 lb. per ton per degree of curvature for cars and 1.4 lbs. for locomotives, this to be added to the other resistances, or

R = .7 C (for cars) and 1.4 C for (locos.), (7) where

C = curvature in degrees.

When a train (or any body) has its velocity increased, or accelerated, the inertia of the body comes into play. We can discuss this by considering a time or distance effect. Thus, if we let

S = distance in feet in which acceleration takes place;

t = time during which acceleration is present, in seconds;

V = velocity, in miles per hour produced by the above acceleration from a state of rest, we have

$$R = 70\,\frac{V^2}{S} = 95.6\,\frac{V}{t} \ldots\ldots\ldots\ldots (8)$$

R being the resistance or force needed in pounds per ton as previously. These equations take into account the re-

volving energy or inertia of the wheels and axles. If an increase in velocity from V_1 to V_2 must be considered, we simply write

$$R = 70 \frac{V_2^2 - V_1^2}{S} = 95.6 \frac{V_2 - V_1}{t} \quad \ldots\ldots (9)$$

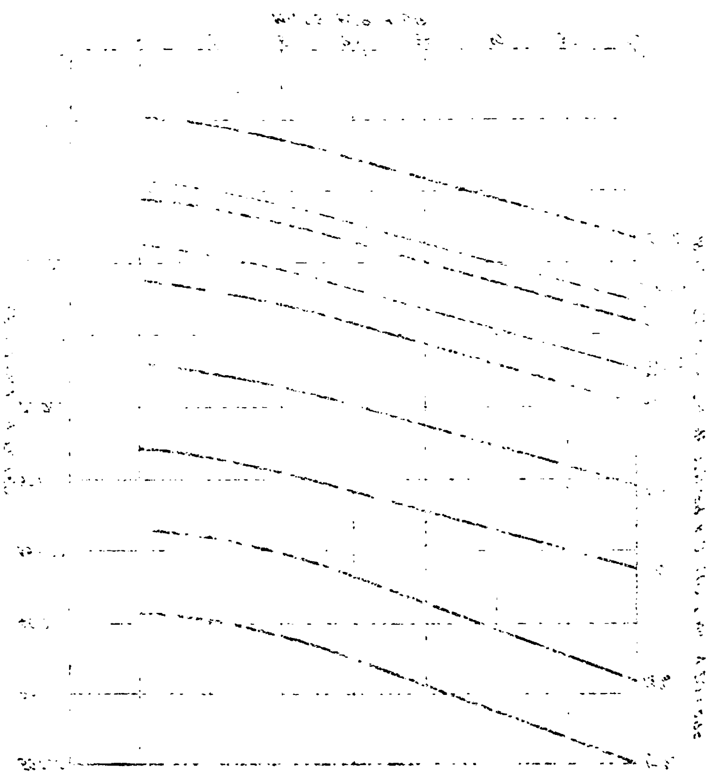
In equations (8) and (9) R is the average force or resistance during acceleration—some portions of the time it may be greater and some less than R.

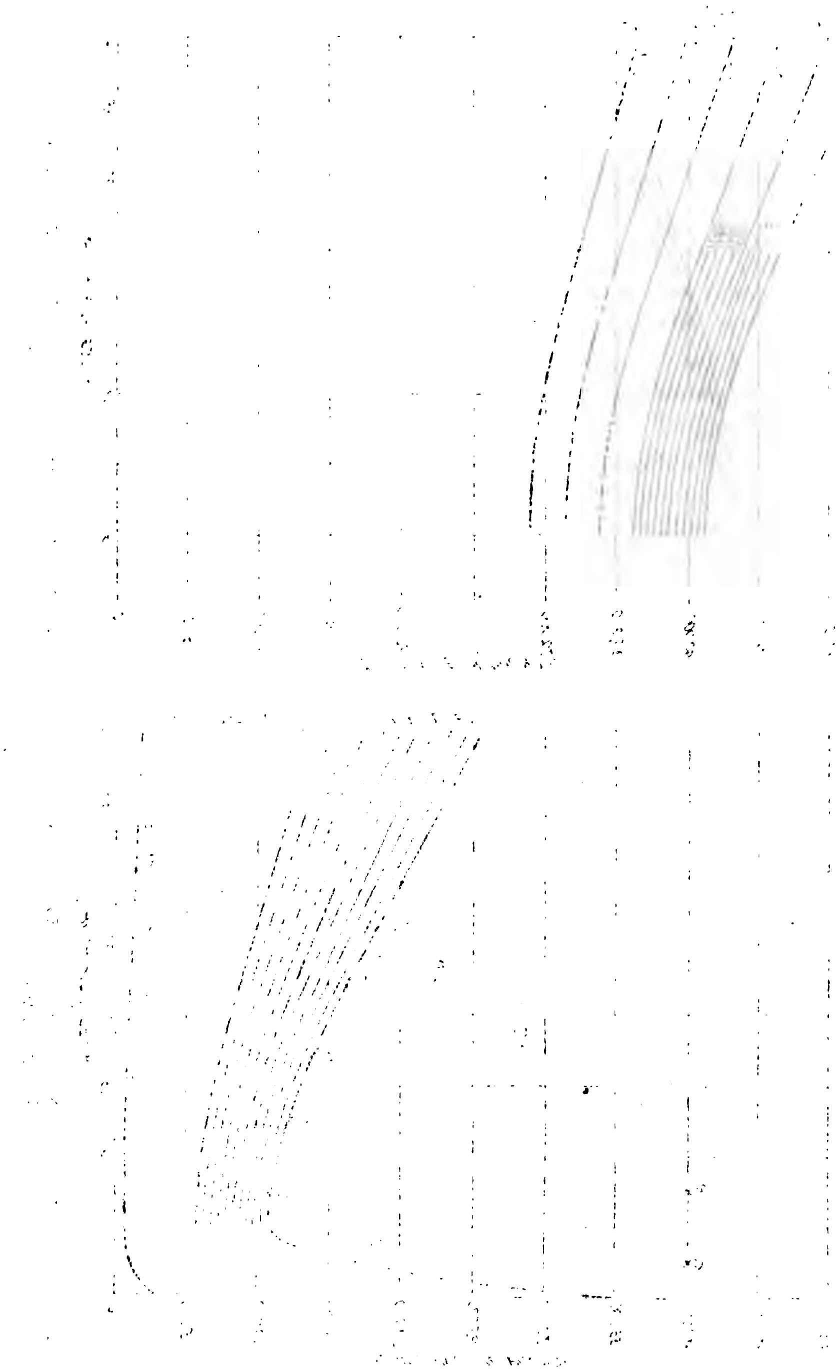
Weather and temperature exert a considerable influence upon the coal pile, as it will be recognized that it is customary to reduce loads under such stress, which means that the load is that much smaller for the same coal consumption, or the same pull on the drawbar. For temperature variations, a number of roads that experience very cold winters make a reduction in the train load of from one-half to three-quarters of 1 per cent. per degree Fahr. below 40 deg.; others arbitrarily reduce ratings 10 or 15 per cent. during the winter months.

In stormy weather, and on the western prairies during heavy winds, the train resistance is so much increased that it is necessary to reduce loads in order to get over the road, this amounting often from 10 to 20 per cent., so that the influence of climate is quite severe upon the fuel bills.

Let us now apply these several formulæ to fuel consumption and find out how the quantity used is affected by them. Fig. 7 shows the resistance in pounds of the engine and tender, and also several weights of trains at various speeds. The abscissæ are speeds given in miles per hour and the ordinates the resistance of the train in pounds, and correspond to the tractive force of Figs. 2, 4, 5 and 6. The diagram is printed on thin paper, so that it can be superimposed on any of the tractive force or fuel consumption diagrams, and the two read together. The lowest curve represents the resistance of the engine and tender at different speeds and was constructed by

(Cut along this line)





passing a line through points formed by multiplying the weight (150 tons) by the value given above for speed resistance, thus at five miles an hour, $150 \times 5 = 750$ lbs., and at 20 miles $150 \times \left(2 + \frac{V}{4}\right) = 150 \times 7 = 1{,}050$. The trains of 1,000 to 2,000 tons back of tender are constructed in the same manner, the weight of engine and tender being added; thus for 1,000 tons net at five miles an hour we have $(1{,}000 + 150) \times 5 = 1{,}150 \times 5 = 5{,}750$ lbs., and for 2,000 tons, $2{,}150 \times 5 = 10{,}750$ lbs. On a 1 per cent. grade, for 1,000 tons, we add the resistance found by formula 6, thus $1{,}150 \times (5 + 20) = 1{,}150 \times 25 = 28{,}750$ lbs., or $1{,}150 \times 20 = 23{,}000$ lbs. more than on the level. This process is followed through for the different speeds and a curve drawn which is 23,000 lbs. greater at every point than the one for 1,000 tons on the level, the effect of gravity, due to the grade, being a constant quantity, and entirely independent of the speed or other factors, as demonstrated by formula 6. The curves for a 1 per cent. grade are shown in Fig. 8.

SPEED.

In order now to determine the effect of speed upon coal consumption, let us combine Figs. 2 and 7, which will give us the results for a simple coal burner. Laying the thin sheet (Fig. 7) over Fig. 2, so that the border lines correspond, we can read off directly the fuel consumption under the different conditions which we have assumed. If we consider a train of 2,000 tons back of tender, on a level, we find that our coal consumption per mile will be approximately as follows:

Speed, miles per hour	5	10	15	20	25
Pounds coal per mile	90	100	125	170	250

These results are obtained by noting the distance between the dotted lines on Fig. 2, where the 2,000-ton

line crosses the lines corresponding to the speeds given, interpolating to establish the pounds of coal per mile. At 10 miles per hour it crosses the 100-lb. per mile line, and the 200-lb. line at about 22½ miles. If we divide these amounts of coal by the weight of train (exclusive of engine and tender) we obtain the quantity per ton-mile, generally given in "pounds of coal per 100 ton-miles," in which case we must divide by 20 as $20 \times 100 = 2{,}000$.

Speed in miles per hour	5	10	15	20	25
Pounds coal per 100 ton-miles	4.5	5.0	6.3	8.5	12.5

This gives us at once an idea of the way in which speed affects the coal pile, although in each case the weight of train is the same, and, of course, the ton-miles hauled are identical, the only thing gained being the quicker movement. At 25 miles an hour we find that the coal used per ton-mile will be more than double what it is at 10 miles an hour.

If we consider 1,000 tons on a 1 per cent. grade, we take the intersections of diagrams 2 and 8 on the line so marked. Thus we find as follows:

Speed in miles per hour	5	10	15	17
Pounds of coal per mile	260	300	430	490
Pounds coal per 100 ton-miles	26	30	43	49

While these amounts are very much larger than on the level (it is only what might be expected) the rate of increase due to variation in speed is about the same. If we wish to determine similar values for a simple oil-burning locomotive, we lay Fig. 8 over Fig. 4 and, find for the 1,000-ton train on 1 per cent. grade:

Speed in miles per hour	5	10	15	19
Pounds of oil per mile	240	243	250	260
Pounds of oil per 100 ton-miles	24	24.3	25	26

Here the increase is not as great, due largely to the fact that we do not have the cinder losses as with coal when the engine is forced.

These problems show us the great increase in fuel bills that may be expected if the speed of trains is increased; if lost time be made up frequently, or a higher class of trains be run requiring quicker movement, the monthly statement is bound to reflect it. A question often asked by managers is "why more fuel was burnt per ton-mile last month than the previous one." If more time has been made up by delayed trains, or a larger proportion of stock runs sent out, there will certainly be an increase in the amount of fuel consumed, and in order to answer such questions intelligently, all the facts must be at hand. This is sometimes difficult for the motive power department, as these records are kept by the transportation department. Of course, there are other causes which may also affect the coal rate, as we have already shown, but considering these to be without change, a variation in the speed will produce great disturbances. At the January, 1900, meeting of the Western Railway Club, Mr. F. H. Clark (Supt. M. P., C., B. & Q. R. R.) demonstrated by results obtained in actual practice that it required nearly twice as much coal *per car* to haul a passenger train of four cars at 48 miles per hour as to haul one of seven cars at 31 miles per hour. This takes into consideration the diminution of the train in order to allow the locomotive to make the necessary speed. If we again place together Figs. 2 and 7, we find that it will require 200 lbs. of coal per mile to haul 2,000 tons on a level at 22½ miles per hour, or the same amount to move 1,000 tons at 37½ miles an hour, in the first case the amount per 100 ton-miles, would be $\frac{200}{20} = 10$ lbs., and in the second $\frac{200}{10} = 20$ lbs. If, however, we should move 1,000 tons only at 22½ miles per hour, we would have a consumption of 80 lbs. per mile, or 8 lbs. per 100 ton-miles. It will be evident that the combination of such diagrams permits the solv-

ing of a great variety of questions, not only concerning the speed variation of trains, but when also interwoven with trains of different weight.

WEIGHT OF TRAIN.

The same diagrams (Figs. 2, 7 and 8) will also enable us to solve problems connected with variations in weight of train, back of tender. The set of curves in Fig. 7 shows the resistance of trains from 1,000 to 2,000 tons in weight, on a level. This does not consider variations in methods of loading, which will be taken up later. At 10 miles an hour we find that the 1,000-ton-curve crosses the 10-mile line at about what would correspond to 50 lbs. of coal per mile, or 5 lbs. per 100 ton-miles. If the load be increased to 2,000 tons, the consumption per mile will reach 100 lbs., or divided by 20, we also have 5 lbs. per 100 ton-miles. As the intermediate divisions for 1,100, 1,200 tons, etc., are uniform, it is apparent that a variation of train load at 10 miles an hour, between the limits stated, will have little effect upon the coal used per unit of movement. If, however, we run at 25 miles an hour, we find for 1,000 tons 90 lbs. per mile, or 9 lbs. per ton-mile, and for 2,000 tons 250 lbs. per mile, or 12.5 lbs. per ton-mile. Here is a decided increase in the amount of coal per unit of work done, caused by increasing the weight of train until we approach the limit of the engine's power, on account of the more rapid rate of combustion needed and the corresponding spark losses. At 1,500 tons we have 10¾ lbs. per 100 ton-miles, so that there is a gradual increase for every 100 tons that we add to the weight of the train.

Let us see now what is the effect on a 1 per cent. grade, shown by the curves of Fig. 8. At 10 miles an hour 1,000 tons will require 300 lbs. of coal per mile, or 30 lbs. per 100 ton-miles; 1,200 tons, 425 lbs. per mile, or

35 lbs. per 100 ton-miles, and 1,400 tons, 700 lbs. per mile, or 50 lbs. per 100 ton-miles. Here the increase is very rapid. Again, if we consider a speed of five miles per hour, we obtain for the 1 per cent. grade 26, 27 and 32 lbs. per 100 ton-miles with trains of 1,000, 1,200 and 1,400 tons, respectively. Returning now to the curves on Fig. 7, and at five miles an hour on the level, we have for 1,000, 1,500 and 2,000-ton trains 5, 4 2/3 and 4½ lbs. per 100 ton-miles, respectively, a *decrease* in the rate of fuel consumption as the load is *increased*. This is due, no doubt, to the dead weight of the engine and tender being distributed over a larger train load, or the weight of engine and tender is a smaller proportion of the total train weight.

These points are very important. It is frequently claimed that heavy trains use less coal per ton-mile than light ones, with the same engine. This is not always true, as has just been demonstrated. There may be so much level track over the division that the benefits of the increased loads, at slow speeds, may be more than sufficient to overcome the expensive effects of grades. However, as a general proposition we may consider that when we approach nearly to the maximum limit of power of the locomotive, the increase in fuel consumption for increasing loads will be large. This is especially so when the full tractive force is being developed. At 10 miles an hour, 1,400 tons may be taken up at 1 per cent. grade with an expenditure of 700 lbs. of coal per mile, or 50 lbs. per 100 ton-miles. If, however, we take 1,430 tons at the same speed, we find that it will require 800 lbs. per mile, or 56 lbs. per 100 ton-miles.

WEIGHT AND SPEED.

Perhaps the most interesting and important results are obtained when we combine the effects of weight of train and speed together. As is shown by Fig. 2 and the

other similar diagrams, when the speed increases beyond a certain point (10 miles an hour in Fig. 2) the tractive force decreases, which means that a lighter train must be taken. Let us now see the effect of speed, when we consider that the engine is in all cases loaded to its full steming capacity. This can be determined by following along the 40,000-lb. tractive force (or resistance) line to the point B, and then down the curve from B to C. By again superimposing Fig. 8 we obtain the combination of train weights and speeds, on a 1 per cent. grade, and fuel consumption. Proceeding as before, we can tabulate the speed, train load back of tender, coal used per mile and per 100 ton-miles as follows:

Speed in miles per hour.	5	7½	10	12½	15	17
Weight of train, back of tender..............	1,450	1,445	1,430	1,280	1,100	1,000
Pounds of coal:						
Per mile..............	500	630	800	650	540	490
Per 100 ton-miles.....	35	44	56	51	49	49

As we increase the speed further the amount of coal per 100 ton-miles also increases. Thus at 20 miles an hour a train load of 800 tons would use 50 lbs., and at 25 miles an hour 600 tons would require 53 lbs. per 100 ton-miles.

When we examine loads and speeds for a level with Fig. 7, we find as below:

Speed in miles per hour..............	27	30	35	40
Weight of train, back of tender.......	2,000	1,600	1,200	900
Pounds of coal per mile..............	300	260	230	200
" coal per 100 ton-miles........	15	16	19	21

These figures show a gradual increase with higher speeds. If we compare these with the changes made in speed only we see that if we reduce speed and maintain the same train load, we will ordinarily burn less coal per ton-mile than if we accompany the drop in speed by an increase in load in accordance with the power of the engine. Thus we consider a train of 1,000 tons on a 1 per cent. grade, which can make with the engine under con-

sideration 17 miles an hour, with a fuel consumption of 49 lbs. per 100 ton-miles. If we keep the same load and reduce speed to 10 miles an hour, the fuel will run 30 lbs., but if we accompany the drop in speed by an increase in load to 1,430 tons (which we can do and still not exceed the power of the engine) it will require 56 lbs. of coal per 100 ton-miles.

These demonstrations make clear the fact that to operate a freight or any train economically, from a fuel standpoint, all the schedule time should be utilized between stations; in other words, use as much time running and as little stopping as possible to adhere to the schedule. Of course, when necessary, time that is lost must be made up, regardless of the coal bills, but as a general proposition the above rule obtains.

GRADE.

In order to study the effects of a variation in grade, Fig. 9 has been prepared. The heavy lines give the resistance for 1,000 tons (in 20 cars) back of tender, and for grades from level up to 1½ per cent. The resistance is calculated by formulæ 4 and 5. Thus for a speed of five miles an hour we have

For train, fT	$= 3\text{x}1{,}000$	$= 3{,}000$ lbs.
For train, 50 C	$= 50\text{x}20$	$= 1{,}000$ "
Engine and tender	$= 150\text{x}5$	$= 750$ "
Total resistance		$= 4{,}750$ lbs.

This gives us the point on the five-mile-an-hour line. If on a ¼ per cent. grade, we simply add $(1{,}000 + 150) \times 5 = 5{,}750$, in accordance with equation 6, making $5{,}750 + 4{,}750 = 10{,}500$ lbs. The remaining lines are constructed in a similar manner. By laying this diagram over Fig. 2 we can obtain the coal consumption, as before. Taking the speed of five miles an hour, which is about as slow as should be figured upon, we find the coal used will be as follows:

Grade in per cent.......	0	¼	½	¾	1	1¼	1½
Pounds coal per mile....	40	85	140	195	250	325	475
Pounds per 100 ton-miles	4	8.5	14	19.5	25	32.5	47.5

If we increase the speed to 15 miles an hour, we obtain different values thus:

Grade in per cent..................	0	¼	½	¾	1
Coal per mile......................	55	110	175	275	425
Coal per 100 ton-miles..............	5.5	11	17.5	27.5	42.5

It will be seen at once that the grade has a very great effect upon the coal bills, and that a hilly road cannot be expected to make as good a showing as a level one. It might be thought that the down-hill portions would make up for the ascents by using no steam on this part of the trip. Let us consider two stretches of road; one level and the other ½ per cent. up for half the distance and down the same amount for the remainder, averaging a level. In the second case, if we admit that no coal will be used running down the grades (which will never be strictly true) the average for the whole distance will be one-half of that shown above, or 7 lbs. per 100 ton-miles at five miles an hour, and 8.75 at 15 miles. On a level the consumption would run 4 and 5.5 lbs., respectively, very much less than with the summit, but having an *average level.*

When studied in connection with speed, we obtain different results, as might be expected. When fast freights are on the road they generally run as rapidly up grade as the boiler will supply steam to the cylinders. From Figs. 2 and 9 we see at once the maximum speed which the engine in question will make with 1,000 tons on various grades, by noting the points where the different curves cross the line B.C. The coal consumption is also taken directly and this, divided by 10, gives the quantity per 100 ton-miles.

Per cent. of grade....	0	¼	½	¾	1	1¼	1½
Speed, miles per hour.	39	31	24	20	17	13	10
Coal used per mile....	210	250	325	400	475	600	800
Per 100 ton-miles...	21.0	25.0	32.5	40.0	47.5	60.0	80.0

At five miles an hour on the 1½ per cent. grade there would be 475 lbs. of coal used per mile and 47.5 lbs. per 100 ton-miles. This table does not show as much variation as the one in which the speed was constant, as the higher velocity on the lower grades adds considerably to the amount of coal used. In estimating the quantity of coal that will be needed to take a train over a given division, each change of grade, when of any considerable length, must be figured separately, and the closer these sections are taken the more reliable will be the results. Of course, what has been heretofore said about waste, condition of engine and quality of coal must all be taken into consideration, as we have shown that they have great influence upon the question.

CURVATURE.

In constructing the lines for resistance, due to curvature, we are guided by equation 7, in addition to that due to speed. For a 1,000-ton train and 150-ton engine and tender we have, on a 5-deg. curve:

1,000x5x0.7 = ...	3,500 lbs.
150x5x1.4 = ...	1,050 "
Total for curvature..................	4,550 lbs.

We simply add this amount to our "1,000 tons on level" line throughout its length, producing the locus marked "5 deg. curvature." For 10 deg., or another amount, we proceed in the same manner.

Taken in connection with changes in speed the curvature produces different rates of coal consumption. Thus at five miles an hour a 10-deg. curve on a level would add to the 1,000-ton train an extra amount of coal of $\frac{120}{10} - \frac{40}{10} = 12 - 4 = 8$ lbs. per 100 ton-miles. At 25 miles an hour the extra rate would be $\frac{260}{10} - \frac{80}{10} = 26 - 8 = 18$ lbs. per 100 ton-miles. Continuous curves, how-

ever, rarely exist for any great distance. Many lines have reverse curves throughout the greater part of some divisions. In such cases, an estimate must be made of the relative resistance of the total curvature, as compared with straight track. When grades are equated for curvature, it is sufficient to use the grade resistance, without reducing it where it is flattened for the curves. That curvature adds considerably to the coal bill there can be no doubt; engines have been stalled on level track by curvature alone, when the train was of great length, and this forcibly demonstrates the extra power required. For lines that are approximately straight, with a few curves of large radius, the consideration of increased fuel consumption may be omitted, but for those that are very crooked it should be taken into account.

LOADING.

As the subject of "Adjusted Tonnage Rating" is now so prominent, we must consider its effects upon the coal pile, or rather upon the amount of coal burned per 100 ton-miles. If the number of tons back of tender remains the same, but the number of cars comprising this load be increased or diminished, the resistance of the train will likewise be increased or diminshed, requiring greater or less quantities of coal for its movement; but as the weight of the train is constant, the result will be a variation in the fuel rate per ton-mile.

In Fig. 10 there are two sets of curves giving the resistance at different speeds of 1,000 tons (back of engine) and the engine and tender, on a level and also a 1 per cent. grade, but with the load distributed in 20, 30, 40, 50 and 60 cars. These were calculated by means of formula 4 for the engine and tender and 5 for the train, as illustrated herewith:

	Load, 1,000 Tons in 20 Cars	
	At 5 miles	At 25 miles
	Pounds.	Pounds.
Train, *f*T	3x1,000 = 3,000	6.75x1,000 = 6,750
Train, 50 C	50x20 = 1,000	50x20 = 1,000
Engine and tender	150x5 = 750	150x8.25 = 1,237
Total resistance	4,750	8,987

	Load, 1,000 Tons in 60 Cars	
	At 5 miles	At 25 miles
	Pounds.	Pounds.
Train, *f*T	3x1,000 = 3,000	6.75x1,000 = 6,750
Train, 50 C	50x60 = 3,000	50x60 = 3,000
Engine and tender	150x5 = 750	150x8.25 = 1,237
Total resistance	6,750	10,987

Now let us consider the 1,000-ton train on a level at 30 miles an hour, and see how the number of cars will affect the fuel rate.

No. of cars	20	30	40	50	60
Coal per mile	210	220	230	240	250
Coal per 100 ton-miles	21	22	23	24	25

At 15 miles an hour on a 1 per cent. grade we have:

No. of cars	20	30	40	50	60
Coal per mile	420	435	450	465	480
Coal per 100 ton-miles	42.0	43.5	45.0	46.5	48.0

We see from this at once that while the adjusted tonnage method enables us to equalize drawbar pull, and to compare ratings between different engines, it does not allow us to make comparisons between the fuel consumption of different engines and trains, unless we allow the tonnage *actually taken* to be represented by a *virtual tonnage,* which would give a definite drawbar pull. Engines that haul trains of large numbers of cars will always show a greater coal consumption per ton-mile than those which handle the same or greater tonnage in fewer cars, but the enginemen should receive no censure on *this account,* as the work is greater, and the train pulls harder

and more coal per ton hauled will be burned. It is well for this to be thoroughly understood in this day of strict comparisons and critical examinations of operating costs.

ACCELERATION.

When a locomotive starts a train from a state of rest, and continues the acceleration, it eventually reaches a speed where the power of the engine and the resistance of the train equalize. When this occurs, the speed will be maintained, but no further increase is possible until the conditions change. While the acceleration is in progress the demand on the engine for power will be much greater than when maintaining a speed below the limiting speed. The amount of such power (*i. e.,* to overcome the inertia of the train) is given by equation 8, $R = 95.6 \frac{V}{t}$, where $R =$ the force needed to overcome the extra resistance due to the increase in speed. The solution of this problem is more complicated than any that we have so far discussed, but it can be performed with the same diagrams, Figs. 2 and 7, for instance, or the others, if we wished to consider oil-burning locomotives. As an example, let us take the coal burner which we have used so far, represented by Fig. 2, and again superimpose Fig. 7.

If we desire to study a train of 2,000 tons weight back of tender, and on a level track, we can refer to the upper line of the set. The dotted portion between 0 and 5 miles an hour shows the resistance at starting, which we have heretofore stated to be about 16 lbs. per ton, dropping rapidly to 5 lbs. at five miles an hour. The power of the engine starts at 40,000 lbs. and so continues up to 10 miles an hour, at point B, when it drops rapidly, as illustrated by curve B-C.

At 27 miles per hour the power and resistance lines

cross each other, so that is the limiting speed for the conditions which we are discussing. At any lower speed the power of the engine (if exerted to its full extent) is greater than the train resistance, so that acceleration is possible. How much is determined as follows:

If we consider first the period from rest to five miles an hour, we must find the excess of power over resistance. The middle ordinate between 0 and 5 miles for speed, and extending from the power to the resistance line, will give us approximately the mean excess of power over resistance. Thus we find that the scale distance from d to d^1 is about 24,000 lbs., and as the total weight of train, including engine and tender, is $2{,}000 + 150 = 2{,}150$ tons, we have $\frac{24{,}000}{2{,}150} = 11.1$ lbs. per ton left for overcoming inertia.

Let us now write formula 8 in the form

$$t = 95.6 \frac{V}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

and formula 9 as

$$t = 95.6 \frac{V_2 - V_1}{R} \quad \ldots\ldots\ldots\ldots (11)$$

It should be remembered that V is speed produced by acceleration in t seconds by force R. From rest to five miles an hour we can therefore write equation 10,

$$t = 95.6 \times \frac{5}{11.1} = 43.1 \text{ seconds.}$$

That is, in 43.1 seconds the train will have reached a speed of five miles an hour if the engine is doing its best. For this period and power we see that coal would be consumed at the rate of 1,250 lbs. per hour, and for 43.1 seconds we should have $\frac{43.1}{3{,}600} \times 1{,}250 = 15$ lbs. of coal.

From 5 to 10 miles an hour the distance from e to e^1

is 29,000 lbs., and $\frac{29,000}{2,150} = 13.5$. Using equation 11,

$$t = 95.6 \times \frac{10 - 5}{13.5} = 35.5 \text{ seconds.}$$

The average coal rate is 4,500 lbs. per hour (as seen by the heavy curves on Fig. 2), and for this time we have $\frac{35.5}{3,600} \times 4,500 = 43$ lbs. of coal. (Here 3,600 is the number of seconds in one hour.)

By proceeding as outlined, we may obtain the time and coal used between any two speeds. Above 10 miles an hour the rate of combustion is 8,000 lbs. per hour uniformly, and the excess power available for acceleration is given by the distance between the points $f—f^1$, $g—g^1$, $h—h^1$, and $i—i^1$ for the different speed intervals. We can tabulate these as shown:

Speed interval.	Time, in secs.	Rate of coal cons. per hour.	Total lbs. of coal used.
0 to 5	43.1	1,250	15
5 " 10	35.5	4,500	43
10 " 15	44.6	8,000	99
15 " 20	68.2	8,000	151
20 " 25	171.1	8,000	380
25 " 27	271.5	8,000	625
0 to 27	634.0	....	1,313

The whole time needed for acceleration from rest to 27 miles per hour is thus $\frac{634}{60} = 10.6$ minutes, and the average rate of fuel consumption will be $1,313 \times \frac{3.600}{634} =$ 7,500 lbs. per hour. The quantity of coal for accelerating between any intermediate speeds is quickly found from the table given, as from 15 to 25 miles an hour we add 151 and 380 = 531 lbs.

BRAKING.

While a large amount of fuel is needed to raise trains to a summit, or to accelerate them to a high velocity (in one case endowing them with potential, and in the other case with kinetic energy) it is not possible to realize anything like this amount of saving when this energy is expended. On easy descents, sufficient to overcome engine and train resistance, but not heavy enough to require braking, no fuel need be used over and above that necessary to care for radiation and leaks. The speed resistance at 20 miles an hour, by formula 4, is 7 lbs. per ton and, from equation 6, we see that a grade of about 19 ft. per mile will just be sufficient to overcome it. ($R = .38\ M$ and $M = \frac{R}{.38} = \frac{7}{.38} = 19$ ft. per mile.) We have previously found, however, that it takes more fuel to ascend a steep grade than it does to run twice the distance on a level, so that a loss is apparent, even if no steam is used in the descent.

If the grade is less than 19 ft. per mile, the engine must work steam to overcome the excess of resistance; if it is much steeper, brakes will be needed in order to prevent undue acceleration. If a stop is to be made on a level in a short distance, the brakes must be used in order to quickly disperse the kinetic energy, and this means that in either case coal must be burned to compress the air required for braking.

In an article by Mr. F. H. Parke (see *Railroad Gazette*, Jan. 29, 1904) it is stated that an ordinary freight car brake cylinder, 8 in. in diameter, with a piston travel of 8 in., consumes about 1 cu. ft. of free air for an ordinary application, giving 50 lbs. per square inch cylinder pressure. If properly handled one such application should stop a train on a level. By knowing the number of cars in the train it is easy to determine the amount of fuel used in a single application stop. If we consider

the train just examined for acceleration, having a weight of 2,000 tons, there would probably be 60 cars back of the tender. The driver brake and tender cylinder would probably be, with the piping reservoirs, etc., equal, approximately, to, say, 12 cars. Then for one stop we should use about $60 + 12 = 72$ cu. ft. of free air. Efficiency tests have indicated in the neighborhood of 3 cu. ft. of free air compressed to 70 lbs. per square inch per pound of steam consumed by the air pump; therefore, we should use for the train which we are studying $\frac{72}{3} = 24$ lbs. of steam for a single full equalization application. We can assume that our coal evaporates 6 lbs. of water for each pound burned in the firebox, in accordance with Fig. 3, so that $\frac{24}{6} = 4$ lbs. of coal would actually be used in making a stop. Leaky train pipes will require running the air-pump even when brakes are not applied, but it would be practically impossible to estimate this amount, unless we knew the speed at which the pump was running. In the tests referred to the pump (an 8-in.) made about 75 strokes a minute and used 5 lbs. of steam. A speed of 150 strokes should never be exceeded, which would require 10 lbs. of steam per minute, or 1 2/3 lbs. of coal. A 9½-in. pump would use about 2½ lbs., and an 11-in. pump 3 1/3 lbs. of coal a minute, if worked at the maximum advisable speed. Some idea of the amount of fuel required to maintain pressure in a leaky train line may be thus gained from the speed of the air-pump. It is not an infrequent occurrence to find the pump working at full speed to maintain the pressure on a long train, and some roads are even applying two air-pumps to a locomotive. Of course, the leaks should not occur, but conditions must often be met as they exist.

STOPPING.

By combining the data under the last two headings we can determine how much fuel it requires to make *a stop*—that is, to stop a train and again bring it up to normal speed. Thus we found that 4 lbs. of coal would be needed for one full application of the brakes on our 2,000-ton train; we previously determined that it would require 1,313 lbs. to accelerate this same train from rest to 27 miles an hour on a level, which with the engine selected would require 10.6 minutes. But in order to state the *effect of the stop* on the coal pile, we must also determine how much would have been used if the train had continued on its way without stopping.

Freight cars are ordinarily provided with braking power up to 70 per cent. of their light weight; locomotives, including tenders, will probably average about 70 per cent. of their weight in working order. The friction of the brake-shoe against the wheel is an uncertain quantity, unless all the elements which enter into the problem are known. (This is fully discussed in "Locomotive Operation," recently published by the writer.) For the purpose of calculation we will consider it equal to 20 per cent. of the applied pressure. In a 2,000-ton train of 60 cars it is probable that the cars and their load would have equal weights, so that we should have for the retarding force back of tender, 1,000 tons $\times$ .7 braking power $\times$ .2 brake-shoe friction $=$ 140 tons, or 280,000 lbs. resistance. For the engine and tender we have 150 tons $\times$ .7 $\times$ .2 $=$ 21 tons, or 42,000 lbs. The total resistance of the brakes will be therefore 322,000 lbs., or 322,000 $\div$ 2,150 $=$ 150 lbs. per ton. The average resistance to motion on the level will average about 8 lbs. per ton, making the total retarding force 158 lbs. per ton. Now we can invert equation 8 and obtain

$$S = 70 \frac{V^2}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

so that we can obtain the distance of the retardation thus:

$S = 70 \times \frac{27^2}{158} = \frac{70 \times 729}{158} = \frac{5,103}{158} = 320$ ft., and from formula 10, the time will be

$$t = 95.6 \frac{V}{R} = \frac{95.6 \times 27}{158} = 16 \text{ seconds.}$$

To determine the distance required in which to accelerate this train to 27 miles an hour, it is necessary to write equation 9,

$70 \frac{V_2{}^2 - V_1{}^2}{S} = 95.6 \frac{V_2 - V_1}{t}$ and dividing each term by $V_2 - V_1$ we obtain

$$70 \frac{V_2 + V_1}{S} = \frac{95.6}{t} \text{ or } S = \frac{70}{95.6} (V_2 + V_1)\ t =$$
$$.733\ (V_2 + V_1)\ t \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

And as the values of V_2, V_1 and t have already been calculated for this train, under the heading acceleration, we can write as follows:

v_1 to v_2	t=	S=	S=
0 to 5	43.1	.733x 5x 43.1	158 ft.
5 " 10	35.5	.733x15x 35.5	390 "
10 " 15	44.6	.733x25x 44.6	815 "
15 " 20	68.2	.733x35x 68.2	1,750 "
20 " 25	171.1	.733x45x171.1	5,650 "
25 " 27	271.5	.733x52x271.5	10,350 "
Total	634.0		19,113 ft.

The total distance from 0 to 27 miles per hour again is evidently $320 + 19,113 = 19,433$ ft., requiring $634 + 16 = 650$ seconds, or 10 minutes and 50 seconds. Now, if the train had not slowed up it would have used 300 lbs. of coal per mile, and as the distance just figured is $\frac{19,433}{5,280} =$ 3.68 miles, the coal consumption for the distance would have been $3.68 \times 300 = 1,104$ lbs., so that by making the stop just discussed the increase in coal used is $1,317 - 1,104 = 213$ lbs. over what would have been needed if no

stop had been made. These calculations require considerable time, but the question is often mooted, "How much does it cost to stop a train?" and it was felt that this treatise would not be complete without considering this point.

WEATHER.

In discussing the subject of resistance we alluded to the fact that is often necessary, from cold or storm, to reduce the rating or load hauled by locomotives. This causes an increase in fuel per unit of work done in direct proportion as the load is reduced, as the engine is expected to exert its regular amount of power in any case. If it be considered necessary to reduce the load 10 per cent., for instance, we shall have an increase of 11 per cent. in fuel per ton-mile, as the full amount of coal will be used on 90 per cent. as much load, and $\frac{100}{90} = 1.11$, or 11 per cent. more coal per ton is allowed. If a 20 per cent. reduction is made we have $\frac{100}{80} = 1.25$, or 25 per cent. more coal for the unit of work. We see at once that such reductions on account of winter or severe weather will be sufficient reason to account for a considerable advance in coal consumption as such season approaches, but it is necessary to do this in order to get traffic over the road; if the load is not reduced great detentions are sure to occur assuming, of course, that the engine has a full rating for good weather. The fact that the weight of the engine and tender is thereby distributed over a smaller train also adds to the increased cost.

To show that this effect is reflected promptly by the reports, we give below the pounds of coal used per 100 ton-miles in freight service (including weight of cars) for the Chicago & North-Western Railway throughout two consecutive years:

Months.	Coal per 100 ton-mls.		Months.	Coal per 100 ton-mls.	
January	25.5	25.0	July	19.0	19.0
February	27.0	28.0	August	19.5	21.0
March	26.0	24.0	September	20.0	22.0
April	22.0	23.0	October	21.0	22.5
May	21.0	23.0	November	22.3	24.0
June	19.0	18.5	December	25.0	24.5

In each year given February required the most coal per unit of work done and June and July the least. No doubt some of the variation was due to traffic conditions, but the general effect of the weather is very prominent throughout the period covered. As it is impossible to say *exactly* how much increase will be caused by weather alone, we shall not attempt to go further into this subject. It is evident that the question of fuel cost is very complicated, if we attempt to allow for all the variations of conditions which may be expected some time or other. The main questions that are likely to arise, however, such as the increase in fuel consumption, due to different schedules of speed, methods of loading, change of grade, etc., are not difficult of solution, especially as they ordinarily represent a *difference* between two or more possible conditions, and while some or many of the various causes which we have noted may arise to seriously affect our calculations as to *total quantities,* they would probably exist under either of the special methods of operation which were being considered, so that the *difference* would not be seriously affected. For such purposes we therefore believe that our methods of computation may be accepted with confidence.

CHAPTER III.

WATER.

While water is a comparatively low-priced article, and according to railroad statements generally, plays an unimportant part in the expense of operation, it is actually responsible for a great deal more in operating charges than it is usually credited with. The trouble is, in some respects, like that stated in the last chapter regarding coal, that a great deal of material is supplied with water that is not water. In coal this ordinarily means that we lose a quantity of heat represented by the weight of the non-combustible elements present, but with water it is much more serious, since besides interfering with the operation of the engine, the objectionable matter may quickly cause the destruction of the boiler itself, the most important part of the locomotive.

QUALITY.

As with fuel, the different kinds of water are numberless, and on most roads no two supplies will be alike. This may or may not be an advantage, depending upon the contents of the several waters of a division, and the method of operating the locomotives. An absolutely pure (distilled) water would probably not be desirable, as its action on the metal of the boiler would be quite rapid. On a railroad in Virginia the waters at the east end are impregnated with tannic acid, which is quite corrosive by itself, but when mixed with the scaling waters farther west, as occurs with locomotives that run through, the effect of one neutralizes the other, producing good results.

To give an idea of the variation in quality of water,

it is stated that there are but two grains of solid matter to the gallon in that of Loch Katrine, Scotland, whereas the water of Great Salt Lake, Utah, contains 22,000 grains per gallon, sea-water averaging about one-tenth of that amount. The quantity that may be tolerated in water for locomotive purposes depends entirely upon the constituents, some being much more deleterious than others. Unfortunately, even more so than with coal, water must be largely used as it is found—that is, a railroad in running through a country, must ordinarily use such water as can be obtained conveniently to the track. This is often overlooked in locating water tanks and pump-houses, the fact that there is *plenty of water* appealing to those in charge of the work, when by some additional trouble and expense, a better water may be obtained. Of course, quantity is of the *first importance*, but it is too often the *only consideration.*

In a general way we may form five classifications of boiler water, as follows:

1. *Practically Pure.*—This includes waters that have little or no scale-forming matter, corroding ingredients, or soluble salts to cause foaming. They may contain sewage or other matter that would render them unfit for drinking purposes, yet would not be detrimental to the boiler. While, for instance, the water of the Chicago river is totally unfit for house use, it is quite satisfactory for steam-making purposes. Many natural lakes and rivers contain practically pure water, and the result is immunity from boiler troubles. One of the lines operating between New York City and Buffalo has water so pure that fire-boxes have been known to last for 20 years, while the average for the United States is perhaps about five years. It is hard to fully appreciate the great benefits which result from the use of good water, and it is worth much expense and trouble to obtain it.

2. *Forming Soft Scale.*—This is the common attri-

bute of waters which contain carbonates of lime and magnesia in solution. When such water is boiled the carbonic acid in the water (which is necessarily present to account for the solution of the carbonates, as they will not dissolve in pure water), is driven off by the heat, and the salts are deposited on the inside of the boiler. These deposits are not hard, but bulky, and as they are poor conductors of heat, they reduce the efficiency of the boiler until they are removed by washing out with a strong stream of water. This causes delay and additional expense.

3. *Forming Hard Scale.*—This is a characteristic feature of water containing sulphate of lime or magnesia, which forms a very hard scale on the water surfaces of the boiler—sometimes as hard as porcelain. It is not precipitated until the temperature of the water is about 300 deg. Fahrenheit; it is a poor heat conductor, and is very hard to remove. When a thick deposit is present, there is a tendency for the parts to become overheated, and leaks, cracks and similar troubles are constant. It is frequently necessary to wash out the boilers every trip, where sulphate waters are in use.

4. *Corroding.*—When water drained from mines is used, there is generally a quantity of sulphuric acid present, which actively attacks the steel of the boiler, and pitting and eating away of the sheets and tubes result. Carbonic acid in solution, chloride of lime or magnesia produce similar results, and these effects are the most dangerous of the severe troubles caused by impure water. Constant washing out and inspection are necessary, involving time and expense, and boiler repairs are frequent and elaborate. Such water should be avoided, if possible.

5. *Foaming.*—This is, perhaps, the most troublesome, from an operating standpoint, of all the burdens that attend the use of impure water. Broken cylinder heads, pistons, rings and valves, blowing packing on pis-

ton-rods and valve-stems, cutting valves and seats, and often the complete destruction of the fire-box itself result from foaming water. It is necessary to carry a very low level in the boiler—sometimes below the bottom of the gage glass, and this is often responsible for dropped crown sheets and ruined locomotives. It is practically impossible to remedy, except by distillation, as the salts, generally sulphate of soda and chloride of sodium or calcium, cannot be removed by precipitation. Distillation will remove them, but if fuel is high it may be an expensive process. However, the matter is so important that it is worth more attention than is generally given to it. If there are over 50 grains of soluble salts to the gallon, trouble is sure to follow, and the cost of such consequent damage will often equal the additional expense for providing good water.

PRICE.

While ordinarily the price of water is low, there is a great variation in this item. If the railroad company owns a good spring near the track, so that it can run water by gravity to the tank, the cost will be practically nothing; if however, it must be purchased from a city or water company, the price may be anywhere from 3 to 20 cents per thousand gallons; if the water has to be hauled, it may cost from 20 to 50 cents a thousand gallons, and even then it may be a continual source of expense.

The first cost often receives too much and the after result too little attention. This can be illustrated by a case that occurred in the State of Iowa. The city at the point in question asked a rate for water which the company thought was too high, so their engineers drove a 70-ft. well, from which water was obtained *apparently* at lower cost. There is no question but that the water cost *less in the tender,* if not after it passed *through the boiler.* The relative values of the two waters, however, are apparent if we compare their analyses:

Grains Per Gallon of Water.

	City supply.	Railroad well.
Carbonate of lime	4.74	24.39
Carbonate of magnesia	1.41	1.18
Sulphate of lime	.78	6.22
Sulphate of magnesia	.54	13.33
Alkali chlorides	.67	1 21
Alkali sulphates	2.97	5.58

The city water was a comparatively good one—the company well caused trouble by scaling, both hard and soft, and so great was the annoyance that it was finally considered preferable to use the city water at the increased figure, and prevent the continual washing out and leaking of the engines.

Many roads now make it a rule to establish no new water stations until the supply has been sampled and examined by the chemist, and this practice cannot be too well commended, as much trouble and expense may be saved later on.

As there may be much time and money expended upon the water after its purchase or in curing its evils, we must consider these in their turn.

PUMPING.

The cost of pumping water depends upon the quantity handled, the height and distance through which it is transported and the cost of the fuel and attendance. A gravity supply will need no power or attendance, and will cost nothing for placing in the tanks. At the Detroit meeting in 1899 of the Association of Railway Superintendents of Bridges and Buildings it was stated that from reports submitted by different railroads the cost was apparently 5.5 cents per thousand gallons when pumps were operated by steam, and 1.5 cents for gasolene engine pumps. As a comparison, it was further suggested that water could be pumped as cheaply with coal delivered at the pump-house for 60 cents a ton as with gasolene at 10

cents a gallon, considering the cost of fuel only. The smaller amount of labor usually needed for a gasolene pump is also in its favor.

It is evident that much depends upon the size of the plant. Small steam pumps may use as much as 15 or 20 lbs. of coal per horse-power hour, while gasolene engines take about one-tenth gallon of fuel. At this rate, with coal at $1.50 a ton and gasolene at 10 cents a gallon, the fuel costs would equal each other. The actual cost must include labor and repairs as well as fuel.

The Chicago & Alton has gone very extensively into the use of gasolene pumping engines, and a remarkable reduction in cost has followed. From a circular issued by the Otto Gas Engine Works we find as follows:

Cost of Pumping Water Per 1,000 *Gallons.*

Place.	Steam.	Gasolene.
Joliet	6.14 cts.	3.01 cts.
Pontiac	9.40 "	2.74 "
Mexico	4.05 "	2.82 "

The saving for the line averaged between two and three cents a thousand gallons for November, 1903, when about 60 per cent. of the steam plants had been replaced with gasolene engines, against November, 1900, when there were only two such stations. In examining the table (not reproduced) given by the Otto Gas Engine Co., it is evident that the saving is mostly in the reduction of labor, as the cost of supplies are higher now than previously. This is not to be wondered at when we remember that the C. & A. runs directly through a coal country, and should be able to obtain very cheap fuel.

Where the wells are deep the "air lift" process is often adopted. This requires an air compressor, which may be driven by any source of power or kind of fuel; the labor or attendance would be considerable in any case, as the compressor would have to be watched. In a plant having a capacity of 1,500,000 gallons in 20 hours, and a total lift of 75 ft., with coal at $2.00 per ton, the

estimated cost is 1.1 cents per 1,000 gallons, and this includes an allowance for depreciation and interest on the investment.

It naturally follows that each point must be considered by itself, and in connection with the existing conditions and the cost of fuel and labor. Perhaps 5 cents a thousand gallons for pumping alone would be a high average cost, but if the water itself does not have to be paid for, and is not delivered under pressure, this would probably be a fair figure upon which to base cost in the supply tank.

WATER TREATMENT.

When locomotives were small and had a comparatively easy time, little attention was paid to the material in the water, but as they became larger and were forced to work more continuously, the trouble increased. In desperation over leaky flues and cracked fire-box sheets, the method of introducing soda-ash, or carbonate of soda, into the tender, and so to the boiler, became quite general, and is still used at many places. In time, however, it came to be recognized that the boiler of a locomotive was hardly the place to do this work of freeing the water from impurities, as the sludge filled the lower part of the boiler, necessitating very frequent blowing off and washing out, and the more logical method of preparing the water before it was delivered to the tender became popular. There are quite a number of treating plants at present in use; in some the apparatus is patented and in others it is home-made. All, however, depend upon chemical action for their success. The soft scaling waters, containing carbonate of lime or magnesia, held in solution because the water itself is charged with carbonic acid gas, are simply treated with slaked lime, which unites with the free carbonic acid, forming carbonate of lime. This, being insoluble in water free from carbonic acid, settles as a white precipitate, accompanied by the carbonate previously in

the water in solution. The clear water is drawn off above the sediment, and thus none of the carbonates get into the boiler, but practically pure water is delivered. As quick lime (from which the slaked lime is made) is a cheap substance, the cost of chemicals for such treatment is small. As one pound of carbonate of lime requires a little more than half a pound of quicklime for its precipitation, we may say, roughly, that for each grain of carbonates in a gallon of water, we should need one-tenth pound of lime for treating 1,000 gallons, this referring, of course, to the incrusting carbonates of lime and magnesia. With lime at 50 cents per barrel of 200 pounds, a water containing 40 grains of carbonates of lime and magneisia, would cost but one cent for the necessary amount of quick lime; the cost of labor would depend mostly upon the size of the plant, as a large one would require no more attention, perhaps, than a small one. The hard scaling waters are more costly to treat by six or eight times. Sulphate of magnesia alone does not form boiler scale, but when present with carbonate of lime a reaction takes place and sulphate of lime is formed. When 300 degrees temperature is reached, this is precipitated, making a hard, cement-like coating on the flues and sheets. In order to remove these sulphates from the water before it is supplied to the tender, it is treated with carbonate of soda, or soda ash, as it is commonly called. The chemical reaction produces carbonate of lime and sulphate of soda, so that the carbonate of lime will settle as before. As one pound of sulphate of lime requires .85 pound of 58 per cent. soda ash for its precipitation, it will require one-eighth of a pound for each 1,000 gallons containing one grain of the sulphate per gallon, and as soda ash is worth about one cent a pound, we could treat only eight grains per gallon for one cent per thousand gallons. The cost of treatment will thus be seen to depend entirely upon the ingredients in the water.

Corroding materials, such as acids and chloride of magnesium, may be neutralized with quicklime or soda ash, chloride of magnesium requiring about the same amount of soda ash as sulphate of lime.

Many of the large railroads in this country have now gone very extensively into water treatment. The Southern Pacific has made, by Mr. Howard Stillman, a very complete organization for this work and reports are constantly issued on this subject. From some at hand it appears that the cost of chemicals varies from one to five cents per 1,000 gallons. They grade the waters as follows, according to the grains of incrusting matter per gallon:

Good, less than 12 grains per gallon.
Fair, 12 to 20 grains per gallon.
Poor, 20 to 30 grains per gallon.
Bad, over 30 grains per gallon.

Mr. G. M. Davidson, of the Chicago & North-Western, has taken the matter up actively, and states the cost at from 1 to 10 cents per 1,000 gallons. The Union Pacific costs have been stated by Mr. J. B. Berry from one-third cent up to 3½ cents per 1,000 gallons for chemicals only. On the Santa Fé, while the majority of waters would need for chemicals, from 1 to 5 cents' worth per 1,000 gallons, some waters ran higher, in one case reaching 21 cents. This latter, however, it was not practicable to treat, and it was abandoned as a water station.

While carbonate waters can be easily and cheaply treated, and a comparatively pure water supplied to the boilers, it is not so with sulphates of lime and magnesia. After the reaction, the carbonate of lime formed settles to the bottom of the tank, and can be blown off as "sludge," but the sulphate of soda, the soluble result of the chemical change, goes into the boiler, and, if in large quantities, or allowed to become concentrated by evaporation, causes foaming. Soluble matter of over 30 grains per gallon

will be likely to give trouble on a locomotive, on account of the constant agitation, although 50 or 60 grains can be endured in a stationary boiler. This is illustrated by the analyses before and after treatment of a water from a driven well, in the middle west:

	Grains, per gallon	
	Before treatment.	After treatment.
Carbonate of lime	24.39	2.26
Carbonate of magnesia	1.18	.88
Sulphate of lime	6.22	.....
Sulphate of magnesia	13.33	.....
Chloride of sodium	1.21	1.27
Sulphate of soda	5.58	26.32
Incrusting solids	46.88	3.54
Soluble salts	6.79	27.81

Here we notice after treatment an increase of 21 grains per gallon in the soluble salts—slightly greater than the sulphates of lime and magnesia (which total 19½ grains in the raw water), but the carbonates have practically disappeared. If we take a water such as the following, which is found in the southeastern part of Colorado, we are sure to have trouble after treatment:

	Per gallon. grains		Per gallon. grains
Carbonate of lime	10.67	Sulphate of magnesia.	13.52
Sulphate of lime	19.01	Sulphate of soda	17.82
Carbonate of magnesia	1.13	Chloride of sodium	1.17

This water untreated will form a hard scale on account of the sulphate of lime; if treated with lime and soda ash, the carbonates can be settled and drawn off, but there will remain in solution from the sulphates of lime and magnesium about 33 grains of sulphate of soda, in addition to the 17.82 grains already in the water, making a total of about 50 grains, which would certainly give trouble from foaming.

The Southern Pacific does not think it advisable to treat water if the soluble alkalies exceed 30 grains per

gallon (whether naturally contained or introduced by chemical reaction), as troubles from foaming in road service with time losses included may largely exceed the cost of boiler repairs due to incrustation. As an example of this, one of their California waters which analyzes as follows:

	Per gallon. grains		Per gallon. grains
Carbonate of lime...	12.42	Sulphate of magnesia.	10.67
Sulphate of lime.....	2.39	Sulphate of soda.....	11.32
Carbonate of magnesia	2.97	Chloride of sodium...	9.32

is considered by them as untreatable, for the reasons given above, viz., that if the sulphates of lime and magnesia were changed to carbonates and sulphate of soda, the soluble salts as a total would amount to over 30 grains per gallon. Another California water contains but 12 grains of carbonates and practically no incrusting sulphates, but has 45 grains of salt to the gallon, and is considered untreatable also. Under such cases it seems that nothing but distillation will get rid of the matter in solution. Tannic acid and boiler compounds have been tried, but they are only partly successful.

DISTILLATION.

Under ordinary conditions the cost of this method of purification would be prohibitive, as can be plainly seen by a few simple calculations. Good coal should evaporate 10 lbs. of water for each pound burned, from and at 212 deg. Fah., at atmospheric pressure; 1,000 gallons, weighing about 8,000 lbs., would therefore require 800 lbs. of coal, and at $1.00 a ton this would mean 40 cents a thousand gallons for fuel alone. Multiple effect stills, however, can be procured, which will reduce the fuel consumption. The Yaryan apparatus will distil water at the rate of about 40 lbs. per pound of coal, and the Goss still will double this. Under these latter conditions 1,000 gallons of water would require $\frac{8000}{80} = 100$ lbs. of coal, and

at $1.00 per ton the cost for fuel would be 5 cents. As in the treating plants the labor would depend upon the size of the plant, and as there are many railroads that obtain their coal at less than $1.00 a ton it is apparent that conditions may exist where the cost of distillation will not exceed that for chemical treatment, and the latter is not available for foaming waters. Such a still was experimented with in the California desert on water containing over 350 grains of soluble alkali per gallon, and this was readily reduced to a workable strength—that is, less than 30 grains per gallon. At this point it was customary to haul water nearly 60 miles, making it cost fully 30 cents per thousand gallons. Fuel could be supplied at this point at the rate of $1.00 a ton, and allowing for labor and repairs the cost of distilled water would run about 13 cents per 1,000 gallons, a reduction of 17 cents under the cost of hauling in trains. There are many places in the west where the combination of cheap fuel and foaming water naturally suggests this method of purification, but for the ordinary carbonates of lime and magnesia the chemical treatment is the proper course to pursue. The cost in any case can be estimated as above outlined.

EFFECTS OF BAD WATER.

If the natural waters are poor and no methods of purification are adopted, there will be contingent expenses created which may be briefly summed up as follows:

Waste of fuel, by blowing hot water from the boiler, in order to reduce concentration.

Waste of fuel, by incrustants fouling the heating surface, and preventing the ready transmission of heat to the water.

Time and labor necessary to wash out the boilers frequently and waste of heat.

Time and labor in making frequent and elaborate repairs to the boiler.

Detention of trains on the road, due to poor steaming and foaming, as well as possible accidents to fire-box, cylinders, pistons, valves, etc.

When the water has natural foaming tendency, or such is caused by the addition of soda ash, the concentration must be kept down by frequently blowing off. Some of the instructions issued in connection with the use of soda ash prescribe that at the end of each trip at least two gages of water shall be blown out of the boiler, and special blow-off cocks operated by air from the cab are provided for the purpose. For a locomotive of moderate size this means that about 4,000 pounds of hot water are to be ejected from the boiler, to each pound of which in the neighborhood of 340 heat units have been added, or a total of, say, $340 \times 4{,}000 = 1{,}360{,}000$ B. T. U. As the efficiency of the boiler will permit, perhaps a utilization of only 7,000 heat units per pound of coal, we find that this represents an amount of fuel of $\frac{1{,}360{,}000}{7{,}000} = 194$ pounds, or about one-tenth of a ton of coal! Besides, it is frequently necessary to blow out while on the road, and this represents further losses.

Consequential losses have also sometimes resulted, by persons or property being damaged while blowing off, when the attachment is on the side of the fire-box. If directed back under the train, it is apt to throw sand, gravel, etc., into the journal boxes, causing hot bearings.

If scale is allowed to accumulate on the heating surfaces there will be a loss of heat, as was referred to in Chapter I, in the discussion of the condition of the boiler. This, of course, depends entirely upon the water used, and the thickness of incrustation. The Illinois Central tests showed only 1/32 inch average thickness of deposit after running the engine 21 months. Many waters would produce this much in a month or less. Professor L. P. Breckenridge, who reported the tests, estimated that

approximately one-fifth per cent. of the fuel burned was wasted or lost for each month that the engine ran between cleaning of the boiler; thus, in ten months the average loss would be about two per cent.; in 20 months, four per cent. This, however, would be very little guide to conditions existing on other railroads, except in the general way, that the dirtier the boiler is allowed to run the greater is the heat loss, and this is chargeable directly to the impure water used.

The cost of washing out boilers is quite considerable, especially if it is thoroughly done, as should be the case, and we may estimate it about as follows:

One hour for boiler washer	25 cts.
One hour for helper	15 "
3,000 gals. water (worth 10 cts. pr 1,000 under press)	30 "
2,500 gals. water for filling up	25 "
½ ton coal, to get up steam at $1.00 a ton	50 "
Total	145 cts.

or, say, $1.50 for material and labor. Washing out has been accomplished with a detention of little over an hour, but we do not think it ordinarily wise to consider less than three hours needed for cooling, washing out and firing up. In oil burners, where the internal brickwork stays hot for such a length of time, it cannot be done under from 6 to 10 hours. If the locomotive costs $15,000, the interest at 5 per cent. will amount to 8 cents an hour, which ought, perhaps, to be considered in addition to the above. However, $1.50 will probably represent the actual cost of this process under ordinary circumstances.

With many poor waters, boilers must be washed out every 600 or 1,000 miles' run, but in *bad* districts this must be done every round trip, say, for each 300 miles. If the engine ordinarily uses 300 gallons of water per mile, at a cost of 5 cents per 1,000 gallons, we should have for 300 miles, $\frac{300 \times 300}{1{,}000} \times .05 = \$4.50$ for the

round trip, so that the expense of washing out would be equivalent to an increase of 33 per cent. in the cost of the water.

Sometimes it is only necessary to change the water in the boiler, in which case the cost would be about half as great, or 75 cents, as seen from our figures above.

The increase in boiler repairs due to bad water is enormous, but is seldom fully appreciated. As above referred to, some lines are able to run fireboxes for 10 or 15 years. There are other cases where they have been replaced within a year. As the cost of applying a new firebox will be between $500 and $1,000, it adds a great burden to the repair account. Again, in the Southwest, flues have been renewed regularly every 60 or 90 days, while in the East they will ordinarily run from one general repair period to another. To show what a difference in expense is caused by water, at Needles, on the Colorado River, the amount of boiler work was cut in half by the introduction of a treating plant at the principal watering point on the division. If these various items are totalized, and the interest for the time engines are out of service added to them, we will be in a position to say how much the water actually does cost, and instead of apparently costing about 5 cents per thousand gallons, it may be 10 or 15 cents.

But the most aggravating part of water trouble is caused by detentions to trains on the road. Poor steaming results from dirty boilers, as has been shown, and foaming causes delays by priming cylinders and steam chests, often causing breakage of the same. It is often necessary to close the throttle before the whistle can be sounded, and water is carried so low to prevent these difficulties, that occasionally a crown sheet comes down—if nothing worse. This is a very serious condition, but it confronts many of our Western lines to-day that have not taken up the purification of water. When these are

duly considered, it will be apparent that we would be justified in going to any reasonable expense to obviate these difficulties and dangers, even to the financial disadvantage of the water department, as a judicious introduction of the proper appliances will not only reduce the cost of operation, but will give a much more satisfactory service, the value of which cannot always be figured in dollars and cents.

The Chicago & North-Western, since putting in treating plants, has not only reduced the boiler work over 20 per cent., but has reduced engine failures 80 per cent. on its Iowa division, which is a great indorsement for the treating system.

WASTE.

That water is usually considered an article of small value may be traced to the fact that leakage from tanks and pipes is often allowed to continue for a considerable length of time. When the staves dry out, or the tank becomes rotten, it is sometimes months before the evil is corrected. As a rule, those losses on the locomotive which have been considered in connection with the fuel, also cause waste of water. Injectors, which continually waste at the overflow, as well as leaks in boiler and tank, may be small in themselves, but when many engines are doing the same thing a large amount of water is lost daily. This all has to be paid for in some way or other, if not by the meter, at least in fuel for pumping, and prompt steps should be taken to reduce it to a minimum.

QUANTITY.

We have now to consider the amount of water used in doing useful work, such as propelling engines and trains on levels at various speeds, up grades, around curves and any combination of two or more of these conditions.

In order to obtain such figures closely to theory, we should proceed in a similar manner to our treatment of the fuel problems, by calculating the cylinder volume at cut-off, weight at cut-off pressure and number of strokes per minute. We could then construct curves in the same way, giving the maximum capacity of the boiler and any desired fractions of this quantity. But the curves which we have already drawn for coal indirectly show the quantity of water, as this was first determined. Thus the curve of maximum power (Fig. 2) indicating 8,000 pounds of coal per hour, may also stand for 40,000 pounds of water, as we saw that at the rate of combustion here considered, viz., $\frac{8,000}{3,200} = 2.5$ pounds per square foot of heating surface per hour, the water rate by Fig. 3 would be 6 pounds, from and at 212 degrees, and allowing the evaporation factor of 1.2, we obtain $\frac{6}{1.2} = 5$, so that $8,000 \times 5 = 40,000$ lbs. of water would correspond to 8,000 lbs. of coal. As the rate of combustion is reduced, the water rate increases. Thus at 6,000 lbs. per hour, the rate of combustion would be $\frac{6,000}{3,200} = 1.87$ lbs., and from Fig. 3 again we find an *actual* rate of $\frac{7.2}{1.2} = 6$ lbs., or $6,000 \times 6 = 36,000$ lbs. of water per hour. If we wish close figures, we have merely to proceed as outlined, but as water is perhaps always cheaper than coal (and usually very much cheaper), when considering the quantities consumed by a locomotive, it will generally be close enough to use a simpler method and obtain approximate results.

We see from Fig. 3 that curves a, c and d lie quite close together—that is, the water rate is not very different for the three kinds of coal represented by these curves, and that for the rate of combustion usually obtaining in

locomotives—from 1 to 2.5 lbs. of coal per square foot of heating surface per hour—the water rate (from and at 212 deg.) is between 6 and 9 lbs., or from 5 to 7½ lbs. actually evaporated at boiler pressure. If we take the mean figure, 6¼ lbs., the greatest possible error, under the conditions which we have assumed, would be 1¼ lbs. of water per pound of coal burned, or if 10 tons of coal were consumed in, say, 100 miles, the quantity of water used during this run might exceed the 6¼-lb. assumption by 25,000 lbs., or say, 3,000 gallons, which at 10 cents a thousand gallons would make a possible error of .30 cents in this distance. As a train-mile will cost at least $1, the error could not be over 3/10 per cent.—too small to notice.

This brings us to a very simple method of determining approximately the quantity of water used, viz., take it as a direct proportion of the amount of fuel. The average actual evaporation for a number of tests of simple coal-burning locomotives was ¾ gallon per pound of coal; but $.75 \times 8.33 = 6.25$ lbs. of water per pound of coal, which is precisely the figure obtained above as a mean of the probable extremes observed in practice. (It is also interesting to note that the highest and lowest results of these tests were .9 and .6 of a gallon, respectively, or 7.5 and 5.0 lbs. of water per pound of coal, also agreeing with our previous determination of extremes.)

From the results of a number of tests made with fuel oil in California, we may safely allow 1¼ gallons of water evaporated to a pound of the oil.

Compound engines usually show a better evaporative performance than simple locomotives for several reasons —the tests used as a reference suggest ⅞ gallon of water to a pound of coal. With oil, as there is little change in the evaporative rate, compounding should not change the constant 1.25 selected above.

When a superheater is applied the ratio of water and

fuel changes for variations in the degree of superheating, and we have tabulated the approximate water rate to be used. The constants for all the cases above considered are here repeated for convenience:

Approximate Quantity of Water Used in Gallons per Pound of Fuel.

Type.	Fuel.	Water.
Simple	Coal.	0.75, or ¾
Compound	Coal.	.87, or ⅞
Simple	Oil.	1.25, or 1¼
Compound	Oil.	1.25, or 1¼

Superheater.

Superheat.	Coal.	Oil.
100 degrees Fahr.	0.70	1.17
200 " "	.66	1.10
300 " "	.60	1.00
400 " "	.50	.83

The application of these tables is so obvious that no example is necessary at this time. Later, when complete runs or trips are calculated, the effect of grade, curvature, speed, etc., will be determined for water consumption, along with the other expenses of operation.

CHAPTER IV.

LUBRICANTS.

The cost of lubricating locomotives is usually not over 1 per cent. of the locomotive expenses, but nevertheless it generally receives as much attention as the cost of fuel—and sometimes a great deal more. When we consider that the latter (fuel) ordinarily runs into expense 30 or 40 times as fast as oil, there seems to be little reason for this anomalous fact, unless it be the peculiar conditions under which lubricants are purchased. Very often there is an agreement with the oil company that lubrication will be effected for a specified figure, and whatever is used over that amount (per engine mile) is supplied free of cost—that is, the extra cost as represented by the excess of oil used is refunded to the railroad when the annual settlement is made. At first sight this would seem to minimize the anxiety to make a *good oil record,* but the incentive lies in the fact that when the contract is renewed in one, two or five years' time, if the refunded amounts have been large the unit price is increased.

As an illustration: A certain railroad was working under a guaranteed cost of oil for locomotives at $1.20 per 1,000 engine miles. The year before the contract expired, owing largely to an increase in the size of locomotives used by liberal purchases of heavier power, the cost (as charged out at the agreed price) ran in the neighborhood of $2.00. While the amount necessary to reduce the cost during the life of the contract was promptly forthcoming, the price was raised in the new contract to $1.82. These statements and documents passing constantly through the hands of the officials are no doubt responsible for the alertness with which oil con-

sumption is watched, as no such arrangement obtains with fuel. In fact, this supervision is carried to such an extreme that at times there is no doubt that a great deal more is expended in fuel and repairs, due to excessive friction and wear, than is saved by economizing in oil; on the other hand there is probably no article used about locomotives that is ordinarily handled as wastefully and ignorantly as lubricating oil, as is seen by the inspection of almost any roundhouse or standing yard.

QUALITY.

As in other articles of commerce, all kinds of oil can be obtained, although at the present time the supply has narrowed nearly down to one make of locomotive lubricant. We do not mean, of course, one grade of oil for different purposes, journals and cylinders, for instance, but that the supply comes from one firm. Some years ago when competition existed it was customary for railroads to purchase oil on their own specifications, but there is comparatively little of this done at the present time.

Ordinarily a high-priced oil will afford better lubrication than a low-priced oil, and if all the material went where it was intended to go there might even be economy in using the high-grade and more expensive article, but when we contemplate the manner in which locomotives are often oiled and consider what proportion goes upon the track, or any place but the journal, the high-priced material does not seem so economical. On account of the difficulty of access of many parts of the engine and the frequent need of oiling moving parts while the locomotive is in motion, by means of a long spout can, while lying on the running board, it is not to be wondered at that much is dropped on the roadbed, and this could just as well be a cheap product. These wastes will always be more or less inseparable from locomotive operation, and

the recognition of this fact probably accounts for many lines using *car oil* on locomotive bearings.

Usually the locomotive lubricants consist of four distinct grades, at about the following prices:

Cylinder oil	48 cents per gallon.
Engine oil	28 " " "
Car oil	18 " " "
Grease	4 " " pound.

Of course, these are liable to fluctuation. Besides, a saving of 2 cents a gallon can usually be made by taking the oils in tank car lots, thereby saving the cost of the barrel, generally $1, holding 50 gallons.

The cylinder oil is compounded to stand high-pressure steam temperatures, and is supposed to remain stable up to 600 deg. Fahrenheit. It is not suitable for journals, although it is very difficult to prevent the men applying it to bearings when they run hot. It is apt to cause hot driving boxes by clogging up the oil passages, as it will not run when cold, and this improper use of a high-priced article adds to the expense. Its sole use should be upon the valves and cylinders of the locomotive and air pump.

Engine oil is intended for the journal bearings and all running parts, and car oil for the tender journal boxes. However, some roads, as hinted above, use car oil for freight and switching engines and *engine oil* for passenger locomotives only, thus saving 10 cents a gallon and keeping down the cost of lubrication accordingly.

Perhaps grease for crank pins, and lately for driving boxes, has done more for the hot-box evil than any one thing in locomotive practice. It not only seems to take a great deal less to lubricate the bearings, but there is not the same chance for waste, the material is not thrown all over the wheels by the motion of the rods, and the heating of journals has been greatly reduced. It has been claimed that grease wears the pins and brasses faster than oil, and while this may be really true it is a fact that

there is less heating with the grease, whereas with oil, when the box becomes hot, it has to be reduced and refitted, and one such operation will remove as much brass as will wear off from the use of grease in running a great many miles.

LOSS.

As above indicated, there is always more or less loss with oil, and it is very difficult to eliminate this feature. As express trains generally make very short stops, it is customary for the engineer to run over one side and the fireman over the other (unless he is engaged in taking water), and the supply is more apt to be liberal than systematic. Then there is a decided tendency, when anything runs hot, to apply cylinder oil, very much greater in cost than the engine oil, and large quantities are so used. Very often the packing (greasy waste) is removed from a journal box, which has been only recently packed, and much oil is thus wasted.

Some lubricators feed very irregularly, it may be flooding the valves at one time, and allowing them to run dry another. Perhaps the force pump is the most regular of the several devices on the market for the purpose of cylinder lubrication, as this delivers an amount which is constant and determinate. The waste does not occur altogether on the engine, as some oil houses with oil-soaked floors will attest. The receipt of oil in tank cars ordinarily stops most of the waste due to leakage, but even here it is necessary to look out for water in the oil. Sometimes it comes over with the compressed air used for elevating from the tank in the basement to the supply faucet, and sometimes with that used to force it quickly out of the tank car into the storage tanks. Modern methods of handling oil, however, have greatly reduced the item of loss in this process, and have also diminished

the cost of labor, so that it is perhaps unnecessary to add any appreciable figure to the price of the oil to cover this point.

HAULING.

Generally this will add a very small proportionate expense to the cost of the oil. If purchased in barrels of 50 gallons each, the weight per barrel will run about 400 lbs., or one-fifth of a ton. At one-half cent per ton-mile rate of transportation the barrel would cost, therefore, one-tenth cent per mile and a 500-mile haul 50 cents. If the average cost of the oil used was 25 cents per gallon, a barrel would be worth $12.50, or with the haul included $13, or 26 cents a gallon, 4 per cent. increase for the 500-mile haul, or approximately we may expect an increase in the *actual cost* of 1 per cent. per 100 miles hauled.

If the oil is received in tank cars the car must probably be returned to the point of delivery, in which case the cost of so doing should be added. However, as an approximate figure, it is believed that above-mentioned allowance of 1 per cent. per 100 miles hauled will be ample.

QUANTITY.

If there was no waste, the quantity of oil used would be quite small. At the 1904 meeting of the Master Mechanics' Association it was stated that by Mr. M. K. Barnum that from tests which he had made he believed that of all the oil applied to locomotive bearings not more than one-tenth part does the actual work of lubrication! However, we will try to determine what amounts could be expected under various circumstances, and first take up cylinder or valve oil.

Naturally, the size of the cylinder and number of strokes should cause an appreciable effect upon the amount needed for lubrication, therefore the larger the

cylinders the more oil that would be required. So, also, if the drivers were smaller and a greater number of strokes of the piston were required in traversing a given distance, the amount of oil would be increased. Thus as an ordinary rule, on account of smaller wheels, freight engines would be expected to use more oil in a given distance than passenger engines with the same size cylinders. It seems probable that the amount of work done by the pistons (outside of that depending upon their size and speed) only slightly affects the oil consumption; that is to say, as much would be required if working at one-quarter as at three-quarters cut-off. It is well known that the most important time to lubricate the valves and cylinders is while running down grade with the throttle closed, the reason for this being that dry steam acts partly as a lubricant itself, and this is absent when the throttle is closed. Therefore it comes about that locomotive lubricators are adjusted as nearly as possible to give equal feeds, whether the throttle valve is open or closed. This would indicate that the "engine mile" is the proper unit for basing the cylinder oil consumption of any particular engine, though as the tonnage hauled depends upon the size of the cylinders the ton-mile unit is satisfactory for comparing engines of different power.

If we simply consider, then, the size of the cylinder and the class of service in which an engine is working, we can tabulate what might be considered a fair average for an engine to make per pint of valve oil.

Engine.	Service.	Cylinder diameter.	Miles, per pint.
Simple	Passenger	17 or 18 inch.	150
"	Freight	17 " 18 "	100
"	Passenger	19 " 20 "	120
"	Freight	19 " 20 "	80
"	Passenger	21 " 22 "	90
"	Freight	21 " 22 "	60
Compound	Passenger	16 and 26 inch.	110
"	Freight	16 " 26 "	75
"	Passenger	17 " 28 "	90
"	Freight	17 " 28 "	60

Ordinarily only the most careful men will attain these figures, and the poorer ones will fall considerably below them. Thus on a large road in the northwest the month of November, 1899, showed for the division using the heavier passenger and freight engines, with 19 and 20-in. cylinders, averages of 63, 82 and 91 miles to a pint, respectively, for each division, these values being the average of freight and passenger service, and on the divisions using mostly 18 and 19-in. engines 108, 81, 105 and 122 miles to a pint. On a road in the southwest, during May, 1903, on one division we found for 18-in. engines in passenger service from 134 to 142 miles to a pint; for 20-in. engines, 72 to 105 miles, and for 17 and 28-in. compounds from 50 to 123 miles per pint of oil. In freight service on the same division the mileage ran for 18-in. engines 68 to 96 miles and for 17 and 28-in. compounds from 25 to 81 miles per pint of cylinder oil. These figures give an idea of the irregular manner in which the consumption of oil varies with different men and the very large effect of their "personal equation." It is quite a common thing to find engineers with absolutely no idea of the amount of oil that should be fed to an engine, and allowing the lubricator to work six or eight times as fast as it properly should, and these circumstances must be taken into account when estimating the probable average consumption.

The amount of engine oil (for bearings) should properly bear some relation to the work performed, as when working hard there is no doubt that more oil is needed, but a distinction like this is very hard to make. The quantity needed by engines of various sizes and types should undoubtedly depend upon the size of the cylinders and the number of journals, as well as the weight of the engine. But these, in a measure at least, are dependent largely upon the size of the cylinder. The number of revolutions is governed by the size of the wheel, and in

going a given distance will ordinarily be greater for freight than for ordinary passenger locomotives. As there is a great uncertainty how much engine or lubricating oil will be used in any case, we therefore observe that we are practically able to use the same basis for estimates as we did with cylinder oil, viz., cylinder diameter and class of service.

By comparing different reports we find that there is ordinarily four times as much engine oil as valve oil used in a given distance, or the mileage to a pint is one-fourth that of cylinder oil. In freight service it may run nearer to one-third. Thus on the division above cited the averages for several groups or runs of passenger engines were:

Miles to a Pint of—	
Valve oil.	Engine oil.
85	19
71	19
102	30
120	27

and for freight locomotives,

Miles to a Pint of—	
Valve oil.	Engine oil.
79	24
55	20
80	33
46	14
39	12
33	11
66	20

Some of the values are extremely low; these were taken from the "pool freights," which generally show less economy in lubrication, as in other supply charges.

If we take the northwestern road by divisions (passenger and freight not separated) we have:

Miles to a Pint of	
Valve oil.	Engine oil.
91	27
82	21
63	23
108	37
81	30
99	25
105	37
93	34
91	38
122	51

showing that our assumption of four, times the amount of valve oil in passenger service and three times in freight, for the quantity of engine oil, is sufficiently close.

As we have stated above, grease is now quite commonly used as a partial substitute for engine oil. So far it has only been generally applied to crank-pins and driving and truck journals. For these purposes it has been eminently satisfactory, and has reduced the cost of lubrication. In rod cups one filling will run for 500 miles or more. Consolidations have been operated, using only one-eighth pound of grease for 100 miles, a service which formerly required a pint of oil. As for equal weights the costs of grease and engine oil are generally the same, the apparent saving is great. In driving boxes it has been found that 2½ ounces per 1,000 miles per box have been sufficient and 1½ ounces for truck boxes, the cost being about one-tenth that of oil and with less trouble from heating.

If we take the prices for oil given previously, we can work up the estimated cost per engine mile, either by assuming that the journal lubrication is entirely of engine oil or so much grease that it cuts the cost of journal lubrication in half and obtain the following totals for the classes of engines just given.

The following table gives the estimated cost for cylinder and engine oil per 1,000 miles, taking cylinder oil at 48 cents and engine oil at 28 cents per gallon and allowing

four gallons of the latter to one of the former in passenger service and three to one in freight, also allowing for use of grease at half rate of engine oil.

Engine.	Service.	Cylinder diameter.	Grease Without.	Grease With.
Simple	Passenger	17 or 18 inch.	$1.31	$0.85
"	Freight	17 " 18 "	1.65	1.12
"	Passenger	19 " 20 "	1.67	1.08
"	Freight	19 " 20 "	2.07	1.41
"	Passenger	21 " 22 "	2.23	1.45
"	Freight	21 " 22 "	2.68	1.84
Compound	Passenger	16 and 26 "	1.82	1.18
"	Freight	16 " 26 "	2.19	1.49
"	Passenger	17 " 28 "	2.23	1.45
"	Freight	17 " 28 "	2.68	1.84

These figures may be taken as a guide, but not as absolutely correct, as conditions may vary them considerably. Thus it was found that the fast mail on one of our principal roads used three times as much oil as the average of the passenger trains over the division, the engineer being particularly anxious that no delay should occur, due to hot bearings. It is likely, however, that he used amounts greatly in excess of his actual needs. This would indicate that high-speed trains are likely to use more oil than slow-speed trains for the same amount of power developed. The effects of grade apparently are very slight upon oil consumption, as it requires about as much when running down hill as up grade.

The temperature has, no doubt, considerable influence upon the conditions of lubrication, and it is usual to use summer and winter grades of lubricating oil—the latter is much thinner, and if applied in warm weather will give trouble by running off, and also not providing sufficient viscosity for the separation of bearing and journal. These results, however, are too indefinite to embody them in estimates of cost.

CHAPTER V.

WASTE.

This is the smallest item of those accounts regularly kept by railroads; in fact, it is so insignificant that it is now usually classed under the general head, "lubrication" or "oil and waste." Notwithstanding, it is a subject of considerable importance in its proper application and use, as the liability of hot-boxes and consequent train delays depends very materially upon the kind of waste used and the method employed in packing the cellars. Very often a freshly packed box will not run as cool as one that has been running for several days, and a good rule is to leave it alone until it shows signs of heating. The proper amount of inspection to determine that the waste is sufficiently oily and that it is in contact with the journal is, of course, perfectly proper, but if the packing is in good shape it had better not be disturbed. The driving boxes of a high-speed locomotive are extremely sensitive, and while some will run for months without giving any trouble others cause annoyance continuously. This is ordinarily due to some defect in material or finish, but it is often very hard to remedy.

QUALITY.

There are nearly as many kinds of waste as lubricants, and they are sold at as many prices. Ordinary cotton waste is perhaps the cheapest, costing 3 or 4 cents a pound. Wool waste is more expensive by 50 or 100 per cent., and there are places where one will not answer for the other. For instance, wool waste should be used in driving-box cellars, as its elasticity keeps it against

the journal, where ordinary cotton waste lies "soggy" in the bottom. Steel wires are sometimes mixed with waste to give it life and help to maintain it in contact with the journal; in other cases hair is used, also asbestos fibres. Certain patented packings cost as much as 12 cents a pound, and may or may not be worth the price, depending upon the general results obtained.

Wool waste is not suitable for the tops of driving and truck boxes, where cotton waste, on account of its "deadness," lies on the box and prevents the dust and dirt penetrating to the bearing, while not interfering with the application of oil, as it holds it and permits it to percolate through the waste to the cavities, and so to the bearing. Where grease is used, however, waste is not needed, as the former has ample body, and it is held against the revolving parts by pressure, either by a screw plug, as in rod cups, or by springs when used in driving boxes.

Waste used in cellars and journal boxes should be thoroughly soaked in oil and the surplus allowed to drain off before it is used as packing, and the proper knives, etc., are needed to apply it to the journal. This is fully as important as the question of quality, and the service obtained depends upon the faithful performance of this work.

Waste used for wiping parts of engines may be the cheapest kind of cotton waste—in some places rags are used for this purpose, and probably quite as satisfactorily, as nearly any soft material will answer for this work.

QUANTITY.

After the boxes have been properly packed the amount required for regular maintenance is small, and the best way is probably to include it, as far as cost is concerned, under the general head of "oil and waste." From a report of the Chicago & North-Western Railway, rendered when the oil and waste were charged separately,

the cost varied on different divisions from 1-10 to ¼ that of oil, the average for the whole road being 1-7; that is, where the oil cost $2.10 per 1,000 engine miles, the waste amounted only to 30 cents for the same distance. The oil and waste should ordinarily vary proportionately for engines of different size, so that if we take the waste at one-seventh of the cost of oil, we cannot be very far from the truth. With grease so little waste would be needed that it may be omitted. We should then obtain the total cost of oil and waste per 1,000 engine-miles approximately as below:

Engine.	Service.	Cylinder diameter.	With waste.	With grease.
Simple	Passenger	17 or 18 inch.	$1.50	$0.85
"	Freight	17 " 18 "	1.88	1.12
"	Passenger	19 " 20 "	1.90	1.08
"	Freight	19 " 20 "	2.36	1.41
"	Passenger	21 " 22 "	2.54	1.45
"	Freight	21 " 22 "	3.06	1.84
Compound	Passenger	16 and 26 "	2.08	1.18
"	Freight	16 " 26 "	2.50	1.49
"	Passenger	17 " 28 "	2.54	1.45
"	Freight	17 " 28 "	3.06	1.84

These figures compare tolerably well with practice. In November, 1899, the average cost of oil and waste per thousand miles was $2.40 on the Chicago & North-Western, no engines having larger than 20-in. cylinders. In February, 1903, the Lake Shore averaged $2.90 for freight and $3.20 for passenger engines. This road has some very powerful passenger locomotives, and that these have put up the cost is evident from the fact that the year previous the same item amounted only to $2.70. For the years 1901 and 1902 the Santa Fé figures were $2.29 and $2.40, all classes of service averaged, a number of heavier locomotives having been added during this time.

While the cost of lubrication naturally increases with the size of the engine, it must be remembered that more work is done, and when reduced to a ton-mile basis, upon which profits are figured, the results may look very dif-

ferent. Thus for a main line and a branch division of the Santa Fé during January, 1903, with average tons back of engine of 702 and 416, respectively, the cost of oil and waste per 1,000 engine-miles was $2.80 and $2.40, but the cost per 1,000 ton-miles was .40 and .58 cents. Here we find an increase of the main line over the branch engines of 16 per cent. *per engine-mile,* but a decrease of 30 per cent. *per ton-mile,* which is certainly the most accurate basis of comparison of the two.

As above stated, we cannot take these figures for oil and waste as accurate for any particular road, as there is always a great variation between the highest and lowest figures; but in estimating the comparative cost of operation of various sizes of locomotives they should represent the facts close enough for general purposes. If the cost or quality of the oil is different from what we have assumed, the final figures would need adjustment, but most roads are now using the same kind of oil on locomotive equipment throughout the country, so that there should be little need of modification in the values given.

Many roads keep an account of the cost of lubrication by individual enginemen, and if one is extravagant he is asked to explain the reason. A new box, or refitted rod, is often a cause for increase in lubrication, but it should average up for the same service in one or two months.

CHAPTER VI.

TOOLS.

The tools usually supplied to locomotives include not only hammer, wrenches and chisels, but the various assortment of oil cans, lanterns, signals, scoops, firing bars, torches, etc. While not strictly tools, they are included under this general designation. After the engine is once equipped the cost of maintenance should be very small indeed, but in reality it is often quite large, and the amount does not bear any relation to the size of the engine, but rather to the disposition of the men upon the engine.

It is important, in the first place, that the tools should be made of the proper material. Perhaps the greatest wear comes upon the scoop or coal shovel. Some roads have specifications for these scoops, defining the weight, size and quality of material to be used, actually designating the chemical composition of the steel of which the scoop is made and the method of riveting it to the handle. While these scoops do not cost very much, on account of the large number used, it is important to see that they are not maltreated. For this reason it is customary, when a fireman needs a new one, to make him bring in the old one as evidence that it has not been ruthlessly destroyed. Before this was done it was quite common for the shovels to disappear altogether—they would either go into the fire-box (of course, accidentally!) or land in the ditch alongside of the track. The oil cans are apt to be very short-lived, unless made of heavy material. One and two-gallon tin supply cans are of little service, as the necks get broken off and the sides knocked in with very short service. This can be improved by the use of sheet

steel cans, which are now placed upon the market. Sometimes torches are given out at a surprising rate. The writer recollects one case where the company had adopted a new pattern, which took the fancy of the men so quickly that the old models were thrown into the ditch or broken intentionally, so that the new style might be obtained.

Marker lamps are often damaged by being used as a foot-step in reaching the headlight, and it seems like a business proposition to make everything about a locomotive strong enough for a man to stand upon.

One road furnished each locomotive with expensive traversing jacks—that is, a screw jack mounted on a base upon which it could be moved by means of a screw and ratchet. They were so seldom used that they were generally rusty and inoperative, and cost a considerable sum to put them in order at frequent intervals.

The small tools should be kept locked up in metal boxes upon the tender, or turned in after each trip to the care of an attendant. Some roads check up the tools turned in after each trip, and if any are short or broken hold the engineer to account for same. This encourages care on the part of the engineman and reduces materially the cost of such supplies, but on the other hand it means an outlay for the wages of such inspectors. Where engines are assigned to one or two crews, there is generally little trouble about loss of tools, unless they are actually stolen from the box. This is not an uncommon feature. An official of the Pennsylvania, while traveling in Ireland, is said to have met a man one night carrying a lantern on which was moulded the letters P. R. R., indicating that the bearer was a "Pretty Rough Rascal" in actuality.

Where pooling exists it is very necessary to keep strict watch over the engine tools, as they will be distributed about the road regardlessly, and engines will go

out without the proper equipment, and in case of trouble much delay and inconvenience will ensue.

As may be surmised from the foregoing, it would be impossible to give a figure for the maintenance of locomotive tools that would have anything like a general application. It will vary more with the section of the country and the type of men employed than with the size or style of the engine. When the men are naturally careful the cost should be insignificant. Where they are unruly and careless the figures run quite high. One road kept account of the supplies furnished to the individual enginemen and prepared a statement each month, giving the expense in this line by each man. In those cases where the withdrawals seemed excessive or above the average he was asked to explain and improve his methods. It is only by constant surveillance that these costs can be kept down to a reasonable figure, and this requires eternal vigilance.

As it is customary to include tools and miscellaneous supplies under one head in the acounts of railroads, the actual cost to be allowed will be worked up together with the items included under the next heading.

CHAPTER VII.

MISCELLANEOUS.

The miscellaneous supplies ordinarily include the various tools which we have just discussed, and other movable articles which usually go with the locomotive, such as lampblack, packing material, sand, soap, switch keys, metal polish, torpedoes, etc.; in fact, it generally covers all the articles except fuel, water and lubricants. In the monthly statements of locomotive expenses gotten out by many roads water is often excluded altogether, and does not appear in such statistics, probably being charged to a water supply account, although it properly is a locomotive operating charge just as much as coal or oil, but it is probably never charged individually, as no means are provided to ascertain how much is used by any engine or class of service. As with tools, these supplies of a miscellaneous character bear little ratio to the size of the engine, but more to the diligence of the men.

The cost of "tools and supplies" is sometimes stated in two ways—the cost per "turn" or per "engine handled," which means the number of times that engines come into the roundhouse, practically the number of trips made and the cost per engine-mile or ton-mile. If we were seeking a strict basis for comparison, we would probably find that a combination of the ton-miles made and the number of trips completed would be required for our foundation, as they both affect the cost, so ordinarily a long run or division would be expected to cost more per turn and less per *ton-mile* than a short one. This is apparently borne out by comparing two contiguous divisions of the Chicago

& North-Western, where the freight traffic is nearly the same, but one division having much longer runs than the other. For a number of months we find that the charge, "tools and supplies," is smaller per *ton-mile* for the division with the long runs than for that with the shorter runs. The figures are as follows per 1,000 ton-miles:

	Per 1,000 ton-miles						
Short runs	$0.0027	$0.0034	$0.0025	$0.0026	$0.0019	$0.0027	$0.0020
Long runs	.0021	.0025	.0022	.0022	.0015	.0019	.0017

The tonnage per engine-mile was not greatly different on the two divisions, but it was somewhat in favor of the short run section, *which had the highest costs.*

In the *Railroad Gazette,* February 19, 1904, appeared an article by C. H. Fry on costs of locomotives at terminals, and from this we find that the supplies are given for one road at one cent an engine turned. As these figures are the same throughout the turns included, they excite some suspicion, especially as very little can be put upon an engine for this amount. This is more than likely the cost of labor connected with sanding engines, etc., rather than the cost of supplies themselves. By figuring over several statements it seems as if an average would be in the neighborhood of 20 cents per trip for tools and supplies.

Coming now to the cost on a mileage basis, comparison of a number of statements from both Eastern and Western roads, reveals a variation of from .13 to .34 cents per engine-mile, with the average between .20 and .21 cents. But half of these various costs lie within 10 per cent. variation from .20 cents, so that if we consider one-fifth of a cent per engine-mile as the cost of "tools and supplies," we are not likely to be far from the truth, although individual cases may vary considerably. If we consider that a locomotive comes into the roundhouse once a day on the average, and makes 3,000 miles a month, or 100 miles a day (which is not far from the

ordinary conditions in this country), we should have $\frac{100}{5}$ = 20 cents per trip, which checks with our former assumption.

Besides the regular miscellaneous articles there are others which may or may not add to the expense of operation. Oil-burning headlights are very cheap to operate, but if we want a better illumination we must go to acetylene or electricity. The cost of operating these lights per hour seems to run about as follows:

Oil	¼ cent per hour.
Aceytlene	½ " " "
Electricity	2½ cents " "

The latter, when run by a small dynamo, as is generally the case, exerts its influence on the coal pile, and with fuel costing $1.50 per ton the expense will be about as given above. While this is the most expensive, as far as actual cost of operation is concerned, the illumination is immensely greater, being estimated at from 50 to 100 times that of oil; for equal quantities of light, therefore, it is much the cheaper, considering illumination. There are one or two disadvantages connected with the use of the electric headlight, however, and one is, if for any reason it is inoperative, the darkness seems much more intense, as the previous illumination was so great. If the apparatus is carefully installed and maintained, there need be little of this trouble, and for passenger locomotives there is no doubt that it is the most desirable light. On double-track roads it occasions certain discomforts to engineers of opposing trains, and it is very difficult to judge the distance of an approaching train, the light being so intense.

In warm climates the acetylene light is quite satisfactory, but in the north it is subject to a certain amount of trouble from freezing. The illumination is much better than with the oil lamp, but, of course, it cannot approach the electric arc.

Steam heat applied to the cars of a passenger train and supplied by the locomotive is another item of additional cost, though quite small. In some tests made by the Gold Car Heating & Lighting Co. on the Northern Pacific Railroad in extremly cold weather, by catching the drips from the cars, it was found that 62 lbs. of water per car per hour were obtained; ordinarily it would not average over 50 pounds, so that if we assume 10 lbs. of coal burned on the engine per car per hour, in addition to the regular amount needed for moving the train, we will be on the safe side. With 10-car trains this would be only 100 lbs. per hour, and while it should not be noticeable to the engineman, it exists and must be provided for. Of course, if there are leaks in the train pipe, as sometimes occur, especially at the couplings, the amount will be increased.

Electric lighting of trains, whether the current is generated by a steam engine and dynamo in the baggage car, or whether the generators are driven by the axles of the cars, places an increased coal consumption upon the engine. The Northwestern Limited trains between Chicago and St. Paul were lighted by the former method, the current in use during the evening representing about 15 kilowatts, or 20 horse-power. If each car is lighted with 600 candle-power, there will be about 2,400 watts required, or, say, 3 horse-power per car, and this will represent in round numbers about 15 lbs. of coal per car per hour. Of course, this figure will vary, but this is perhaps an average condition.

Under certain conditions there may be other items to which we have not specifically referred, but while they cause some increase in the cost of operation it is not, as a rule, large. These figures do not include repairs or maintenance of any of these special appliances, but merely the amount of supplies necessary to operate them.

Freight trains ordinarily contribute few extra drafts upon the locomotive, unless it be in the matter of leaky air-brake pipes, which has been referred to previously.

There will be an extra amount of water used to correspond with the coal consumption noted, but the value of this is so slight that it would be a useless refinement to consider it for our purpose.

CHAPTER VIII.

GENERAL REPAIRS.

Probably no portion of our study is of greater interest than the question of repairs, yet it is one that defiies every attempt to bring it to a scientific basis of comparison. We know in a general way that large engines are more costly to maintain than small ones, such as were used twenty years ago; that certain special types or designs are more troublesome to keep up than others; that labor and materials are higher priced in the west than in the east; that certain sections of the country, on account of water, fuel, or physical conditions, cause more frequent repairs, and that heavy trains (overloading) cause breakdowns and damage to the locomotives, but when we attempt to analyze these factors in detail and determine *how much effect* each has upon the general question of repairs, we find ourselves hopelessly stranded.

If we attempt to analyze statements and statistics regarding the cost of repairs, and wish to unravel the why and wherefore of each statement, we enter a labyrinth of detail and investigation that will be as unproductive as it it laborious. The enormous number of factors entering into this proposition is such that many of them cannot be assigned positive values, from which any close attempt to estimate beforehand the probable cost of repairs for any given locomotive in any specified locality will be fruitless. It often happens that two or more locomotives, exactly alike, are put on the same runs, and in the first year one of them will cost two or three times as much as the others. This is frequently laid to the carelessness

of the men handling the unfortunate engine—it often happens that the blame should be divided between the engineers and the builders of the machine, who, perhaps, have slighted some of the workmanship, or supplied defective material. Some engines continually break frames or cylinders, while others, apparently identical in every way, give no trouble. Of course, there is a reason for all these things, and it is allowed that many of them should not be permitted to exist, but they *do exist*, and the best that we can do is to recognize them and correct them as fast as possible.

However, as in the case of losses in fuel, all engines have some troubles, but some usually do not have all, so that for a large division the matter is likely to equalize itself, and the average may remain fairly constant. Thus for the year 1899, the cost of repairs and supplies per engine mile on the Chicago & North-Western ran between 3 and 4 cents each month during the year, but did not touch either of those figures. Some roads think that a regular appropriation will suffice to cover the cost of repairs, but as wrecks and unforeseen contingencies are likely to arise, distorting the average for the particular month, it is not recommended. Our caption, general repairs, must not be taken in the strict sense in which it is ordinarily used by railroad shops, but for our purpose must include everything which cannot be properly considered running repairs. It is customary on some roads to consider all general repairs when the cost at any one time reaches a certain figure—sometimes $750. While this may be of some benefit in classifying the amount of work done, it is of little actual value, unless all the conditions are known, and also the mileage since the previous general repairs.

Some railroads regulate their shopping by the mileage which the engine has made since the last shopping. In this system the mileage made is posted each month on a card, and the additions of the previous months

are made, and when the shopping mileage is reached the engine is withdrawn from service. We believe the better way is to have the condition examined and reported each month, as the actual condition is at all times more important information than the bare mileage. For example, we would expect ordinarily that passenger locomotives should make 120,000 miles and freight engines 80,000 miles between general repairs, but even this is ambiguous, as a large portion of the mileage may be with light trains, or with very heavy ones, as the case may be. Then there may be a condition when the fire-box needs renewal, from some sudden failure, the engine having made not over 30,000 or 40,000 miles since being overhauled, whereas the machinery may be good for six months' further work.

In order to provide for these contingencies as well as to keep track of the work which the engine has done, the writer introduced the cards shown below, in addition, of course, to the monthly condition statements:

Engine No.......... Class........... on...........Division,
in............service..............miles since General Repairs
should go to.........................Shops.............for
Boiler Repairs..
Flue Repairs..
Machinery Repairs.......................................
Tire Repairs..
Wreck Repairs...
Engine is now...........................190........
..................................M. M.

(SIDE A.)

Engine No............... Class...............
Ordered to......................Shops.............190....
Arrived at......................Shops.............190....
Taken in........................Shops.............190....
Ready for service...................................190....
Sent to.........................Division...........190....
Remarks ....
....
....
Cost of Repairs........................ $............

(SIDE B.)

As the locomotive approached the condition where a shopping was needed, a card was filled out (see side A) by the Master Mechanic to whom the engine was assigned, giving the general details and present location of engine and shop to which, in his judgment, she should be sent, and this was mailed to the superintendent of motive power. These cards were to be sent in at least a month (if possible) before the engine should be withdrawn from service, and especially if the grade of repairs necessitated sending the locomotive to a large shop on another division. This afforded opportunity to properly regulate the class of work sent to the different shops, and to give special instructions regarding the repairs. It also called attention to the mileage made, and if this was small gave a chance to call for explanations as to the condition of the engine.

Side B was used while engine was being shopped, and when completed the time and cost of the work indicated whether the instructions had been complied with or not. These cards were filed in a "card index tray," and thus the last shopping of any engine, with cost and other general points, could be immediately ascertained, and when the next card arrived indicating that a shop period was needed, this and the previous card gave very valuable information regarding the engine. While $750 might have covered the cost of general repairs some years ago when locomotives were much smaller than they are now, and when labor and material were both lower in price than at present, comparatively little can be done for that sum at this time. From a statement before us, made in 1902, one of the best-managed roads in the northwest shows $1,000 for general repairs for some 17 by 24 in. engines, which were supposed to represent average conditions. For 19 and 20 in. cylinders the repairs run higher—$1,200 to $1,500 per engine. When a new firebox is needed these figures are increased by from $500 to

$1,000, depending largely upon the necessary boiler work accompanying the insertion of the new fire-box, as at times it is found advisable to renew certain shell sheets which have deteriorated. In the southwest where labor is much higher paid and often not so effective, the cost is likely to run 10 or 20 per cent. greater.

The relative proportions of labor and material entering into the cost of repairs are, of course, not fixed, and vary usually from equal halves to two-thirds and one-third; that is, the cost of labor will ordinarily lie between 50 and 66 per cent. of the total cost of repairs. There are cases when it may be less, or more, but we think an assumption of 60 per cent. for labor and 40 per cent. for material will not be far from the general average. When locomotives are rebuilt—that is, receive new boilers and many parts of machinery—the cost may run up to 30 or 40 per cent. of the original price—in some cases more, depending entirely upon the nature and extent of the work done.

It has been generally recognized that the last few years have been extremely expensive ones for the railroads. In a communication to the Railroad Commissioners of Texas addressed by the International & Great Northern Railroad in 1903, the statement was made that during the past five years the average wages of employees had increased 15 per cent.; prices of material had increased 53 per cent.; prices of locomotives, 56 per cent., and prices of cars, 26 per cent., yet in the same period the freight rates had *decreased* on an average, 21½ per cent. These increases have been a source of much anxiety to railroad officials, and the only method of offsetting these conditions is in the erection of modern shops and the purchase of up-to-date machinery. This means a large outlay, but it is well justified by the results if made with discretion.

Of course, the size of the engine must be considered,

as a large locomotive cannot be overhauled for the same cost as a small one, and the repairs should be considered in connection with the work accomplished. The old method of basing repairs on the engine mileage is really of little value unless the size and power of the engine be also considered. On the other hand, the ton-mileage is not altogether satisfactory for two reasons: It does not cover light engine mileage, which certainly causes some wear to the parts, and it does not tell us whether the full power of the engine has been in use, or only a part of it.

If the general repairs of a locomotive cost $1,000 and cover a period of 100,000 miles, the rate of such repairs will be one cent a mile. (This does not include running or roundhouse repairs.) If the fire-box must be renewed every 100,000 miles, which actually occurs under some adverse conditions, the rate will run 1½ cents or more per mile. In sandy sections and on heavy grades the mileage may run only 50,000 or 60,000 miles between such repairs, increasing the cost to 2 or 3 cents a mile. In some bad water sections flues have been renewed every 90 days, or, say, 10,000 miles. As this costs in the neighborhood of $300, the flue work alone will add 3 cents a mile to the repair charges. Of course, the obvious remedy is to treat the water so that the flue trouble will not exist, but then we may get into transportation difficulties even more troublesome. In fact, there is perhaps no locomotive account that depends upon the physical conditions of the road and the manner of loading and operating the engines as much as does the cost of repairs.

The method of treating the engine after it has been brought into the shop is also very important. It is well known that the longer an engine remains in the shop the more it will cost, largely due to the fact that the ordinary mechanic has little interest in the accurate distribution of labor, and also to the tendency to "find work" to do as

long as the locomotive remains in the shop. Remarkable improvements both in time and cost of doing work have been made by a system of scheduling the work beforehand and providing each department with a date when the different important parts *must* be ready. This insures smooth and uniform progress of the engines through the shop and avoids the delay due to waiting for materials from the different departments.

In one of our large shops in the northwest where this system has been in conscientious operation for four or five years, the time of general repairs has been reduced from one month to 13 days, and yet this shop is not provided with traveling cranes, nor is the work paid for by the piece. This is merely referred to in order to illustrate the importance of proper system and organization in all branches, if the best results are to be obtained. Of course, modern machinery must be provided, and high speed tool steel, with the proper help for the foreman to see that all tools are constantly running at the correct speed, as no matter how ample the facilities, if an efficient *personnel* is lacking, the shop cannot be a success. Examples of this are seen at the present time, where in spite of the expenditure of large sums for improvements, the output of the new shop is very discouraging, and is a source of adverse criticism to the motive power department.

Complete co-operation is necessary between all the departments, and probably nothing inspires this quicker than regular meetings of the shop foremen, with the master mechanic, where improvements in the service and modern shop practices are freely discussed and trials of same encouraged. The manufacture of repair parts in large quantities reduces the unit cost and makes necessary turret lathes and duplicating machinery. The scrap pile affords a vast field for study and generally such investigations, if carefully made, will bear fruit. The

judicious use of malleable iron instead of brass will often constitute quite a saving, and even some brass castings are made very much heavier than actually necessary.

It would be out of place here to attempt any lengthy discussion of shop methods, and the benefits resulting from up-to-date practices, but the important part which they bear to cost of repairs is readily recognized and will be appreciated

CHAPTER IX.

RUNNING REPAIRS.

These repairs are quite as difficult of satisfactory interpretation as general repairs, as they follow no general rule of common application. Some engines require work upon them every day, while others need it only at infrequent intervals. In the *Railroad Gazette,* February 19, 1904, Charles H. Fry gave the cost of handling locomotives at terminals for a number of different roads. In some cases the repairs were stated separately, from which we can obtain an idea of this cost. On the Norfolk & Western, for the first six months of 1902, the cost for repairs per engine handled ranged from $0.96 to $1.06, and for the same period of 1903, from $1.20 to $1.37 per engine, on the average. The Mobile & Ohio, for July, 1903, averaged $0.61 for the whole line, though at one point the cost was $1.89. The Wabash System, for June, 1903, showed an average of $0.98, different divisions varying from $0.62 to $1.36.

For June, 1903, the Seaboard Air Line showed an average of $1.13 per engine handled. Several other roads, the names of which were not given, show for running repairs $2.83 and $2.50 per engine handled, the latter figure being stated to cover an average of 125 miles run per engine.

These figures indicate that the running repairs will probably cost from one to two cents per mile run, depending largely upon the facilities provided and the cost and quality of the labor employed. Then, of course, it must be remembered that the roundhouse work at some points

is much more liberal and thorough than at others, and will be correspondingly increased in cost.

The sum of these two items—general and running repairs—constitutes the total repair cost of the engine. Under the most favorable circumstances, for very light engines, it is not likely to be less than 2 cents per mile run, and in certain cases may amount to 10 or 15 cents per engine-mile. This is a wide variation, but the causes which affect this account are very varied, both in kind and intensity.

On one of the northwestern systems, for a period of one month in 1899, a division equipped with the lightest power cost 1.95 cents per engine-mile, general and running repairs being included, while the divisions having the largest engines (20-in. cylinders) cost over 3 cents, the average for the whole line being 3.18 cents per mile, while three years later the average had reachd nearly 4 cents per engine-mile. The cost of repairs per 1,000 ton-miles hauled back of tender at this latter period was 19 cents for passenger and 9.5 cents for freight engines, the former costing double the latter, showing the effect of speed and weight of train, the passenger trains being only a little over one-fourth as heavy as the freight trains.

On a road running east out of Chicago in February, 1903, passenger engine repairs averaged 5.60 cents and freight engine repairs 7.22 cents per engine-mile, or 22.88 cents for passenger and 7.73 cents for freight engines per 1,000 ton-miles. In this case the freight trains were over four times as heavy as the passenger trains, which accounts for the freight locomotives costing more for repairs per engine-mile, but less per ton-mile.

A mountain division of a southwestern line showed for January, 1903, 8.25 cents per engine-mile and 14 cents per 1,000 ton-miles. These were very heavy locomotives, but the train tonnage was only about one-half that of the Chicago road, so that while the repairs per engine-mile

were only slightly greater, they were nearly double per ton-mile, this indicating the important part played by grades with this account. On the same system, but farther west, engines of the same size and build cost 50 per cent. more, as the water was very troublesome and fuel oil added greatly to the expense of boiler maintenance.

One of the southeastern lines shows as follows:

Year.	Average tons per engine in freight service.	Average cost of repairs Per freight-engine mile.	Per 1,000 freight-ton miles.
1897.........	251.43	6.41 cts.	25.4 cts.
1898.........	266.17	6.36 "	23.9 "
1899.........	277.96	6.04 "	21.7 "
1900.........	279.92	6.05 "	21.6 "
1901.........	336.11	6.82 "	20.3 "
1902.........	322.95	5.88 "	18.2 "
1903.........	302.71	6.54 "	21.6 "

Here we see that the cost per engine-mile is less than the Chicago road, but the the cost per ton-mile is much greater. This is evidently caused largely by the physical condition or characteristics of the different roads. The Chicago road is nearly level, and can haul trains three or four times as heavy as on this road, which has very heavy mountain grades, and the cost per ton-mile reflects this condition. We also see that as the cost per engine-mile has an increasing tendency, the cost per ton-mile is decreasing.

Again we have different costs of repairs for different types of engines. One large road operating a number of compound locomotives of different types found that one style cost 13 cents per mile for repairs, while the other type cost only 6 cents, the engines being nearly alike in size. It has also occurred that compound locomatives have cost nearly double (per mile) as much as simple engines, also by spending so much time in the shop their annual mileage is very much less. This must not be thought to apply to all compounds, as some have given

very good service, but as a general proposition it indicates the value of simplicity in minimizing the cost of repairs.

UNIT OF COST.

Statistics of the cost of locomotive repairs might be presented in great array, but such figures convey little meaning, without knowing all the existing conditions, and while they may be interesting they are not very instructive. As we have seen, the cost will depend upon a great variety of facts, and neither the engine-mile nor the ton-mile is entirely satisfactory as a unit. For instance, the engine-mile is practically useless as a basis of comparison between engines of different size, and the ton-mile is equally defective if we wish to compare engines on different grades and alinements.

If the locomotives are similar in weight and power, but operate on different lines or different divisions of the same line, the engine-mile unit will be the most satisfactory for purposes of comparison, but if the size and power are different, and the locomotives run over the same sections of road, then ton-mile statistics will be the most valuable. Thus, in searching for a unit for general comparison, we are confronted, not only with the varying size and power of different locomotives, but also the profiles of the roads upon which they operate, and our unit should provide both for the features of engine mileage and ton mileage, as well as conditions of grade, etc.

If we use the tractive force of the locomotive, we have a unit that is a fairly regular function of the size and weight, and it is evident that if the engine is exerting the full tractive force, or only 50 per cent. of it, it is entirely immaterial whether it is hauling 80 cars on a level or 20 on a heavy grade, so long as the engine is exerting the same amount of power.

After studying the question carefully we have con-

cluded that, when exerting a pull on the draw-bar, the cost of repairs will run about one cent per mile per ton of draw-bar pull, or tractive force at the circumference of the drivers. This unit might be termed a "draw-bar ton-mile," or more exactly a "tractive force ton-mile," and must be distinguished from ton-mile of train back of or including the engine. This unit is entirely independent of the rate of grade or curvature, and is merely the force of one ton acting parallel with the rails and at the circumference of the drivers through a distance of one mile. When the lever is in the corner, and the engine is doing its maximum work, the cost of repairs would be proportional to its maximum tractive force, and when the rate of expansion is increased, reducing the available tractive force, the cost would be proportionately diminished. It is not likely that an engine would continuously exert anything like its full power—perhaps not more than 40 per cent.—for the average time that it is working steam. Under such a supposition we should have the cost of repairs per engine-mile about as shown below:

Approximate Cost of Locomotive Repairs per Mile Working Steam.

Maximum available tractive force.		Cost: At full tractive force.	Cost: At 40% of max. tractive force.
10,000 lbs.	5 tons.	5 cts.	2 cts.
20,000 "	10 "	10 "	4 "
30,000 "	15 "	15 "	6 "
40,000 "	20 "	20 "	8 "
50,000 "	25 "	25 "	10 "

These figures do not seem unreasonable in the light of our past investigations; but we must also allow for running with the throttle closed, as down hill, for example, when it is certain that there will be some wear on the machinery. This, we think, may be set at one cent per engine-mile. We could then write the estimated cost of repairs after making a reasonable mileage, and which should include both general and running repairs, under

ordinary conditions, and with the ordinary types of locomotives, in the form of an equation, as follows:

Let F = maximum available tractive force as found in equation 3, but expressed in tons of 2,000 lbs.

n = average proportion of F exerted throughout the period.

m = miles run for the repair interval,

then cost $= n\,F\,m + m$ in cents or $= m\,(n\,F + 1)$ . . (14)

In order to make clear the application, let us assume an engine of 40,000 lbs. tractive force in helper service, where it is worked at full stroke up a grade, and then drops down without using steam. On the uphill portion n will equal one on the downhill run, $n = 0$. Consider that the hill is 20 miles long. Then we should have for the cost of repairs necessary for an uphill trip,

$m\,(n\ F + 1) = 20\,(1 \times 20 + 1) = 20 \times 21 =$ . . . \$4.20

For the downhill trip, $20\,(0 \times 20 + 1) = 20 \times 1 =$ .20

For both trips (one round trip) \$4.40

or $\frac{440}{40} = 11$ cents a mile for the average, which seems to agree fairly well with practice, although a close approximation to any special case could not be expected.

Again, if we have a passenger engine whose tractive force is 10 tons, and which averages 40 per cent. of this during its entire working period, we should expect the repairs to cost $(n\ F + 1) = .4 \times 10 + 1 = 5$ cents per mile.

In text this formula might be easily remembered as one cent per ton of tractive force per mile plus one cent per engine-mile.

Mr. Virgil Bogue suggestes a formula in which the cost of repairs and stores would be equal to .1728 times the tons on drivers, corrected by the proportion of average load to full load. With the general proportions of locomotives, wherein the weight on drivers is 4 or 5 times the tractive force, the cost by this rule would be

somewhat less than by ours, when the engine was fully loaded; however, as he uses higher percentages for the average power exerted by the engine, the two methods produce results not very far apart.

The most difficult part of the proceedings is to fix upon the value of n in formula 14, but as the rule itself is intended only to give an approximate idea of what the cost of repairs will be, it is not necessary to go to too much refinement. Moreover, as pointed out, the cost will vary greatly when the water or labor conditions are very different, for all of which due allowance should be made as heretofore explained. The most useful purpose of the rule is evidently to permit us to calculate the difference in total operating costs, for engines of various sizes over the same division, when we desire to know the relative cost of handling traffic by means of large or small locomotives. In this case any extra flue or fire-box work would probably be a nearly constant addition per mile for either locomotive, so that the *difference* in cost would be generally unaffected. As stated previously, costs of both material and labor vary so enormously throughout the country, or during a single year, that absolute values for totals cannot be expected, but, fortunately, if our rules are logically deduced, the *difference* of costs for various methods of operating in the same district can be determined with sufficient accuracy to enable us to find the cheapest speed, loading, etc., for the territory in which we are interested.

The increase in cost of locomotive maintenance and operation due to the larger sizes of the machine now in use is often commented upon as comparing unfavorably with the reduced cost of transportation charges. There is little logic, however, in such criticism. From our analysis we have seen that it is natural to expect great fuel and maintenance costs when the engine is enlarged. More work unquestionably requires more fuel, and heavier locomotives will certainly cost more for repairs than lighter

ones. We cannot hope, therefore, to greatly increase the size of the power and obtain large reductions in the cost per ton-mile on these two very important accounts; the cost is sure to be nearly in proportion to the work accomplished by the locomotive, which means that the fuel and repairs per ton-mile in the same service will not vary greatly, although there should be some gain in favor of the larger engines.

But with transportation charges this is entirely different. Outside of the switching and yard work a long train requires little, if any, more labor or men than a short one, particularly since the general introduction of automatic brakes, and this fact alone is sufficient to cause a very considerable reduction in the cost of engine and train crews per ton-mile; thus the transportation accounts benefit at the expense of the maintenance charges, and instead of criticisms the fact that the total cost of transportation is reduced reflects credit upon the practice of increasing the power of the locomotives, which alone is responsible for the economical results obtained.

CHAPTER X.

RENEWALS.

This may or may not be an operating charge, depending upon the policy of the road. In the strict sense of the term "renewal" it would be an operating expense pure and simple—that is, if new locomotives were purchased only as the old ones were worn out. The actual life of a locomotive is a very uncertain thing to compute. The author recently saw an engine 38 years old that had just been withdrawn from active service, having the original rods, frames, etc., and in England engines are said to be running in the neighborhood of 50 years old. Generally in this country, when a locomotive is 20 years old, it is supposed to have reached the limit beyond which it is not considered policy to spend much money for repairs, and if the same size and price of engine were purchased with which to replace it, an annual charge of 5 per cent. would create sufficient funds to effect a renewal at the end of the 20-year period. This would be a true renewal charge, and should be added to the ordinary cost of repairs. If the cost price of the engine were 10,000 and a mileage of 50,000 were made per year, we should have an addition of $\frac{10{,}000.00 \times .05}{50{,}000} = .01$ or 1 cent a mile to the repair charges to take care of the regular renewals. But renewals are never handled in just this manner. The new locomotive invariably is larger and costs more money than its earlier prototype, and this in itself constitutes a betterment, instead of an ordinary renewal.

On some lines it is the avowed policy to scrap a certain number of old engines every year, it, of course, being ascertained that there are a large number that are worn

out or antiquated and of questionable service value. When the scrap engines are so reported each month, an arbitrary amount, in one case known to the author, of $17,000 an engine, is charged to the repair account and credited to a replacement fund. It is evident that such an amount as that named above is far in excess of the original cost of the engine which it is used to replace, and if the number scrapped each year be large and the average mileage small, the charges against the repair account may easily reach 2 or 3 cents per mile over and above the normal or actual cost of repairs. There is no criticism intended of the wisdom of such a policy, as it is doubtless the proper one to adopt, and many roads are burdened with a large number of "antiquated freaks" which are worth more as scrap than as motive power, but the importance of the method of replacing locomotives to the cost of repairs must not be overlooked, and it should always be considered in making comparisons of one road with another.

Very often is is not stated in the reports whether replacement figures are included in the repair charges or not, and this fact shows the uselessness of compiling large quantities of statistics when the method of computing them is not known, nor is it even at all likely that they have been worked up on the same basis. While 20 years has been referred to as the probable limit of useful life of a locomotive, it, of course, should be more a question of service than of years. On very few roads will the average annual mileage of all locomotives exceed 50,000 although some engines may make 8,000 or 10,000 miles a month. The author remembers when engine 1001 made two round trips a day on the Pennsylvania Railroad between Harrisburg and Altoona, as an experiment, and kept this up for a number of months. This amounted to 15,000 miles a month. Very frequently schedules are so arranged that a round trip of 150 miles, and in some cases 200 miles each way, can be covered every 24

hours in passenger service. This would correspond to 9,000 or 12,000 miles a month, as the case might be. Under such conditions we should expect these engines to wear out twice or three times as fast as the average for all the engines, and although they would have to be replaced that much sooner, the cost of such renewals, distributed over the mileage performed, would be no greater per mile run. Fifty thousand miles a year for 20 years would make a total of 1,000,000 miles, and if some engines ran 9,000 miles a month, they would reach this figure in about 10 years. The road could just as well afford to replace them then, as to wait 20 years at one-half the annual mileage, and better, because if such service were obtained from all the engines, it is evident that only one-half as many would be needed to operate the road, and only one-half as much capital would be tied up in equipment of this kind. The author believes in wearing locomotives out as fast as possible. By this he does not mean wearing them out by improper treatment or careless maintenance, but by the legitimate work of hauling trains. The faster they can be worn out the sooner they will be replaced with modern machines, and the strides made in the power and type of locomotives in the last few years have been such that an engine only 10 years old is of comparatively little use, except for branch service. It is very much better, if it be possible to so operate the road, to have, say, 50 engines which must be replaced in 10 years, than to have 100 stay in service for 20 years. This is what is meant by wearing them out as fast as possible, so as to reap the benefits of new and improved power.

But there is still another phase to the question which can best be illustrated by an actual case. An important line, having a number of 1 and 1¼ per cent. grades, was operated with power so light that only short trains could be hauled, or of respectable length by double heading. An analysis was made of the freight train movement for

a calendar year, and it was found that if 20 new engines of larger size were purchased the saving in engine crew and train crew mileage in one year would be sufficient to pay the cost of the 20 new locomotives. It was no doubt good policy to make the substitution, and as the line in question was part of a large system, the lighter engines thus replaced could be used on other portions with easier gradients, but the difference between the price of the new engines and the credit received from the old ones would constitute a very large addition to the repair account, unless the difference were charged as a betterment to capital account, where it really belonged. Some roads like the Pennsylvania are continually improving the property and adding to its initial value out of the profits, all of which is sound business, but if these betterments are charged to repair accounts, as they often are, it is absolutely useless to compare operating expenses between different roads or different periods.

Apropos of this discussion a number of new and powerful passenger engines were put on a part of one of our western systems, displacing lighter engines, which were sent to other territories. These being replacements were naturally charged to the repair account. The first year that they were in service each locomotive saved $5,000 by reducing the number of sections and double-headers. This saving naturally accrued to the credit of the transportation department, as it was principally in train crew wages, but motive power costs had risen by the charges made against maintenance to provide for the purchase of the engines.

There are still other times when renewals are required—that is, when from collisions or wrecks the locomotives are either destroyed or so badly damaged that it will not pay to repair them. Such incidents throw heavy charges into repair accounts.

Rebuilding of locomotives, such as the application of larger boilers, cylinders or wheels, constitutes what may

be termed extraordinary repairs, and will greatly increase the cost, unless specifically treated. Even the application of driver or truck brakes, if introduced very generally for a year or so, will add quite a perceptible figure to the repair account. Where statements are regularly prepared and are used for comparisons it is advisable and proper to state whether wreck repairs, extraordinary repairs and renewal fund charges are included in the regular repair expenses, and if so, what they amount to; otherwise the comparisons of one year with another are valueless. As an example of how the repair figures may be affected by such charges, a large western road for one month had a *real* locomotive repair account of $90,000. During the same month there were charged to repairs and credited to the replacement fund $35,000, or 40 per cent.! Another road included $6,300 of wreck repairs in a total of $48,000, so that the wreck damage cost one-eighth of the total repairs for the month.

Under these conditions it is evidently impossible to make any general estimates which are likely to conform to the ordinarily published statements of the cost of repairs, as so much depends upon the policy pursued. It is no doubt fair to allow an ordinary amount, such as one cent a mile for renewals, but it would be out of the question to attempt to carry wholesale purchases of heavier power by any arbitrary figure that might be assigned without knowing the detailed operations and methods followed.

CHAPTER XI.

ENGINEERS.

The effect of enginemen's wages upon the cost of transportation is exceedingly irregular and uncertain in that it bears little, if any, direct ratio to the work accomplished. It is true that the pay is in a measure according to the work performed, as for instance, a rate per mile, which varies at times for different types and classes of engines, the larger locomotives obtaining the higher rates for operation, but at the same time light engine mileage, which produces no direct transportation; overtime, caused generally by side track delays; reporting for duty; constructive mileage, and similar unremunerative (for the company) methods, bring about the fact above stated, that the pay bears little ratio to the work accomplished, if by such "work" we understand the production of useful transportation, or "revenue service," as it might be termed. Strictly speaking, the haulage of empties is not a "revenue service," in that ordinarily no payments are earned by the railroad, yet in this case the engine may do just as much work as in hauling a fully loaded train, and all the locomotive expenses are justly apportioned to such mileage, regardless of the nature of the train. We must therefore discriminate in such matters, and as far as the locomotive expenses are concerned, consider that work done by the tender drawbar is a legitimate credit to such expenses, whether any revenue freight is hauled or not.

SCHEDULES.

The arrangements by which enginemen's wages are computed vary greatly throughout the country, and are

generally more or less complicated. In many cases the men are paid a standard rate for a run of 100 miles or less, so that if the run were but 70 or 80 miles the pay would be the same as for 100 miles, except that special provisions are usually made to cover "turn-around" trips. In addition to this, if the run be over 100 miles, the additional mileage is usually allowed at the same rate.

As examples of these methods, several locomotive enginemen's pay schedules are here reproduced:

SCHEDULE 1.—COMPENSATION OF ENGINEERS IN PASSENGER SERVICE.—*Rate per* 100 *Miles or Less per Day.*

	Districts			
	A.	B.	C.	D.
Eight-wheel locomotives	$3.50	$3.85	$3.75	$3.65
Ten-wheel, less than 50 tons on drivers	3.50	3.85	3.75	3.65
Ten-wheel, more than 50 tons on drivers.	3.65	3.85	3.90	3.80
Prairie	3.75	4.00	4.00	3.90
Mogul	3.75	3.85	3.90	3.80
Consolidation	3.75	4.40	4.00	3.90

Over 100 miles will be paid pro rata.

Here we notice several peculiar features. It might be considered logical enough that more pay should be given for a consolidation locomotive than for a light 8-wheel engine, on the basis that it will do more work (haul more cars), but as far as the engineman is concerned the increase in labor is merely oiling and watching the additional bearings. The same argument will not hold good, however, for the various rates which apply to the same engines when used in different localities. Districts B and C have very much steeper grades, being directly in the Rocky Mountains, and this more dangerous service (claimed by the men), and the fact that the territory is more costly for living with fewer advantages, has always received a higher rate of compensation. While a locomotive will not work any harder (bearing in mind the many miles of drifting) on a hilly road than on a level, yet the descent of steep grades requires greater

attention and carefulness on the part of the men, and may justify an increased remuneration. District D lies in the same general territory as district C, but the grades are lighter, and the rates are less on that account. From schedule I we see that the size of engine, rate of grade and conditions existing in the particular locality are all reflected in the wages paid to the enginemen.

The freight schedule for the same road (lying mostly west of the Missouri River) shows still greater vagaries.

SCHEDULE 2.—*Rate per* 100 *Miles or Less per Day.*

	Districts						
	A.	B.	C.	D.	E.	F.	G.
Eight-wheel locomotives..	$4.00	$4.00	$4.33	$.4.15	$.4.15	$4.25	4.00
Ten-wheel, less than 50 tons on drivers........	4.00	4.00	4.33	4.15	4.30	4.25	4.00
Ten-wheel, more than 50 tons on drivers........	4.15	4.15	4.48	4.30	4.30	4.25	4.00
Prairie..................	4.25	4.75	4.75	4.60	4.60	4.25	4.00
Mogul..................	4.25	4.75	4.75	4.60	4.60	4.25	4.00
Consolidation............	4.25	4.75	4.75	4.60	4.60	4.25	4.00

Over 100 miles will be paid pro rata.

There are perhaps no logical reasons by which these various rates could be justified, but they are brought about in several ways. Sometimes a large road absorbs smaller lines adjacent to its territory. These small roads may have had different rates of pay entirely from the larger line—very often such rates will be greater. On becoming part of the absorbing system the men naturally strive to prevent a reduction in their pay—the large road certainly does not wish to raise the rates of their many enginemen, and so two rates will exist for years in territories that are interwoven.

Again, rates of pay are usually adjusted at regular conferences between the railroad officials and the representatives of the men; the former strive to keep down such rates, while the latter endeavor to advance them—the result is generally a compromise; some rates are raised as a concession, in order to dispose of the question

amicably, or at times to reward some individual engineman who has held a specific run for a long term of years, and so the schedule is formed, to be readjusted whenever the men find it possible to obtain another increase. Under such circumstances a logical or rational disposition cannot be expected.

In addition to the above tables, a specific allowance of 25 cents per 100 miles above the regular rate was made for way freight trains. Helper enginemen were paid \$4.75 for 12 consecutive hours or less, with overtime at 47½ cents per hour. If, however, over 100 miles are made within the first 12 hours, an additional payment of 4¾ cents per mile is made. These rates applied to mountain territory—on the plains, the helper rate was \$3.75 per 12 hours, with the same ratio of extras as above. Thus, if a helper engine made only one trip of 20 or 30 miles in 12 hours, the full pay would be due, so that the rate per ton-mile of train handled would be greatly above the normal, as far as that district was concerned.

Switching enginemen receive from \$2.90 to \$4 per day of 10 hours or less, depending upon the locality. If an engineman be called and not used on account of the train being abandoned, he is paid for 33⅓ miles as per the class of service for which he was called. Light engines call for passenger rates of pay.

Another road in the central west has a complete schedule for practically every run, passenger and freight, graded to heavy, medium and light engines; also for junior enginemen as well as for those entitled to full pay. For extra and special passenger trains the rate is 3.5 cents per mile for full rate enginemen and 3.15 cents for juniors, this term signifying men during the first year of their employment as enginemen. Work train service is entitled to 3.75 and 3.4 cents per mile for seniors and juniors, respectively. An important line operating in the northwest gives a schedule as follows:

SCHEDULE 3.—*Road Service.*

Class of engine.	Passenger.	Freight.	Way-Freight.
Eight-wheel, 18-inch cylinder and under.	$3.80	$3.80	$4.10
Eight-wheel, 19 and 21-inch cylinder....	3.80	3.80	4.10
Atlantic Type..........................	3.90	3.90	4.20
Ten-wheel, 18 and 19-inch cylinders.....	4.10	4.15	4.45
Ten-wheel, 20-inch cylinders............	4.10	4.25	4.55

These rates are for 100 miles or less. For the first year of service the rates are 80 per cent. of those given above. Switching is paid $2.95 and $3.10 for 10 hours or less. All regularly assigned men are guaranteed not less than 2,600 miles per month, except where they may lose time on their own account. Extra men are not guaranteed any definite amount, but catch what they can. This schedule (No. 3) is quite regular and makes no change in the rate for different parts of the road; only the type of engine and class of service affect the pay.

Schedule 4 shows the rates in force in the State of California.

SCHEDULE 4.

	Passenger.			Freight.		
	Districts					
	Mountain.	Undulating.	Level.	Mountain.	Undulating.	Level.
Eight-wheel locomotive..	$3.65	$3.50	$3.55	$4.15	$4.00	$4.05
Ten-wheel, less than 50 tons on drivers.........	3.75	3.75	3.75	4.50	4.30	4.30
Ten-wheel, more than 50 tons on drivers........	3.90	3.80	3.80	4.60	4.35	4.35
Prairie	4.00	3.85	3.85	4.80	4.35	4.35
Consolidation, less than 85 tons on drivers.....	4.00	3.90	3.90	4.95	4.50	4.50
Consolidation, more than 85 tons on drivers.....	4.00	3.90	3.90	4.95	4.50	4.50

These rates are for 100 miles or less per day; all mileage over 100 to be paid for pro rata.

Here will be noted the higher rates paid for mountain lines than for level. The former have some grades of 140 ft. to the mile, while the level run has little over

20 ft. to the mile. The passenger rates are lower than those given in schedule 3, but the freight rates are considerably higher.

SCHEDULE 5.

	Engines, weighing, on drivers		
	Less than 50 tons.	More than 50 tons or less than 60.	More than 60 tons.
Passenger service...	$3.65	$3.75	.....
Freight service.....	4.15	4.25	$4.45

These rates are for 100 miles or less; over 100 miles paid proportionately, and represent the schedule of a line in the far south. Switch enginemen receive $2.90 to $3.10 per day of 10 hours.

One of the eastern roads pays as follows:

SCHEDULE 6.—*Rates per Mile in Cents.*

Passenger service..................................	3.41 cents.
Through freight....................................	4.25 "
Local freight..	4.50 "

For runs of less than 100 miles the company has given a regular list of the compensation for each such run. It also states that when not so provided, runs of less than 50 miles will be paid at overtime rates, based on 37 cents an hour in passenger service, and 42.5 cents in freight service. For runs of 50 miles or over, but less than 100 miles, 100 miles at regular rates will be allowed. This is one of the simplest schedules, in that no allowance is made for different classes of engines. Most of the freight power on this road consists of consolidation locomotives, which probably accounts for the uniform rate in freight service.

By comparing these various tables we find that the passenger engineers receive between 3½ and 4 cents a mile quite generally, but four exceptions to this being found. The freight rates vary more, being generally between 3¾ and 4¾ cents per mile, with a few cases even outside of those limits. The farther west the higher is

the rate paid, as a general proposition, although there are exceptions to this, as seen in passenger rates in schedules 3 and 4.

The practice generally in vogue of paying for 100 miles, even if only 60 or 70 miles be run, has the effect of placing a variable value upon this item of operating expense. It is evident that if many such short runs are made in a month, the actual cost of this service will be greatly increased by the natural operation of the schedule, although no change in the established rates will be actually made. These points require careful watching, and many ingenious arrangements are made locally by the division master mechanics to combine such short runs as will enable the men to make good wages, and at the same time permit them to give a full return to the company. In making any study of train costs it is obviously quite necessary to be familiar with the situation, so that these various irregularities may receive due consideration.

OVERTIME.

The charges made against overtime are often so large as to very seriously affect this item of transportation costs. It is an item that maintains this specific cost at nearly full value, while no work is being accomplished, as occurs in delays either on main or side tracks. When an engine goes into a siding for a length of time that may run from 10 minutes into hours, the consumption of fuel and water drops to the amount required to make up for radiation and leaks, the supply of oil can be reduced to zero, the wear and tear on the machinery ceases altogether, but the pay of the engineman proceeds at full rate—that is, at the overtime rate, assuming, of course, that the time allowed for the run would be occupied without the delay which we are considering. If it be of such short duration that the train can still make its terminal

within the limit for paying overtime, this would not increase the pay of the enginemen, but if the run be extended beyond the time limit, all delays must be paid for at practically full rates.

In connection with schedule 1, we find this rule: "Eight hours shall constitute a day's work for enginemen in passenger service, and no overtime will be allowed until these hours are exceeded. When the schedule for any train exceeds eight hours, all delays, if more than 59 minutes beyond the schedule time, and be paid for pro rata."

In passenger service overtime is not so likely to occur, as these trains are given the preference throughout their journey, to the detriment of the freight trains. In freight service the following rule applies: "Ten hours shall constitute a day's work for enginemen in freight service and no overtime will be allowed until these hours are exceeded. Ten miles per hour shall be considered the running time of all freight trains, and overtime will be paid only on trips, the average speed of which does not reach 10 miles per hour."

From this it is apparent that the hourly rate is one-tenth that given in schedule 2; as under ordinary circumstances 100 miles are allowed, even for shorter runs, there would be no overtime allowed until 10 hours had been occupied, as this would allow a rate of 10 miles an hour, or one-tenth of the schedule rates. Many freight trains, however, are so heavily loaded that they can do little better than 10 miles an hour when running, and therefore every delay must be paid for at full rates under this arrangement. If the trip be made at a greater speed than 10 miles an hour, the engineer obtains the benefit and is paid by the mile or run.

Another road in the central west pays 36 cents per hour for full-rate enginemen and 32½ cents for junior

enginemen, in freight service to accrue only when the average speed is less than 10 miles an hour. In connection with schedule 3, an overtime rate is allowed at 10 miles an hour, as per basis of rate and classification by the schedule. The same applies to schedule 4. Schedule 5 is accompanied by an overtime arrangement, which gives passenger enginemen an allowance of 10 miles an hour on the basis of the 100-mile rate for all delays of one hour or more over the schedule time, when the run is over 100 miles. On runs of 100 miles or less overtime in excess of schedule is allowed when delayed two hours or more over the schedule time. This is quite a liberal provision. One of the runs on this road is 99 miles between terminals and the schedule time about four hours. If a delay of two hours should occur the engineman would receive pay for 100 miles and the overtime would amount to the proportion of 20 miles, or 1 1/5 the regular rate for six hours of time, whereas we found for schedule 1 that no overtime was allowed until 8 hours had elapsed. In freight service overtime is paid at proportionate rate for all time used to complete trip in excess of an average speed of 10 miles per hour.

The eastern road shown in schedule 6 has a uniform overtime rate of 37 cents per hour for passenger enginemen and 42½ cents for freight men. Overtime for through runs begins after being on duty 61 minutes over the running time, when one hour is allowed up to 1 hour and 31 minutes; over this two hours are allowed, and so on. It will be noticed that there are as many idiosyncrasies in the payment of overtime as in the regular schedule, and most of them have been brought about in a similar manner.

Now, what does this overtime amount to in the way of operating costs? This is a question which will have

to be answered by each division for itself. At the last Master Mechanics' Convention (1905) there was presented a report on "Time Service of Locomotives." The time was taken of one engine for one month in freight service, in which the distribution showed as follows:

Time at and in roundhouse	28	per cent.
Running time	29	"
Delays on road and in yards	43	"
	100	per cent.

From this it appears that this particular engine was only in motion hauling its train for 40 per cent. of the time that it was out on the road, and as the men must be paid for time lost, only about 40 per cent. of the enginemen's wages were really applicable to transportation benefits. This case may not be an average sample of what is taking place daily, but we all know from experience that there is usually a great deal of overtime paid, and that it ordinarily represents no benefit whatever to the railroad company. Of course, much of this cannot, possibly, be avoided, due to track and traffic conditions, nevertheless it is unremunerative, and must be considered in the question of costs. A train loaded down by excess tonnage may lose so much time than the overtime for the engine and train crews will be a very serious charge against its operation, and in considering what is an economical loading, the question of overtime cannot be lost sight of if any accuracy be desired.

DELAYED TIME.

This operates in much the same way as overtime, but the term is generally applied to delays in starting or getting away, whereas overtime refers mostly to delays that occur after leaving the starting point. Some roads allow overtime rules to cover all delays by simply stating that

the enginemen's time will commence at the time of departure of train, as designated in caller's book. Another road states that when an engine crew is on the road between terminals for a time not exceeding in hours the mileage of the run divided by 10, they shall be allowed delayed time for all time that they are delayed at initial terminal, provided that time is one hour or more. If the crew shall be on the road for a time exceeding in hours the mileage of the run divided by 10, then their time shall be figured from the time that the crew leaves the initial terminal to their arrival at destination, 29 minutes or less not being counted, while 30 minutes or more is counted as one hour. By this it will be seen that at engineer cannot claim both delayed time and overtime on the same run; if the overtime is greater—that is, delays during the trip amount to more than the time lost in starting—he will naturally take the overtime, but if the run be accomplished without delay, he can claim delayed time if it occurs, although the trip may have been completed at a much higher rate of speed than 10 miles per hour. The first rule given, it is apparent, does not permit such an arrangement, and seems the simplest and fairest all around.

Still another road allows hourly rates for the full delay, whether it occurs in starting or upon arriving at a terminal, provided that it amounts to one hour or more. This is still more liberal, as even if a good run be made, well within the speed limit, a man can obtain in addition overtime or delayed time at both ends of the trip if it occurs.

These delays have nothing to do in general with the weight of the train, but are chiefly concerned in the yard arrangements for making up trains for departure and for putting them away on arrival; however, they must be considered, as they increase the pay-roll without enlarging the ton mileage.

The rate of pay for delayed time is usually the same as for overtime, and there is no reason why it cannot be considered strictly as a species of overtime, and estimated accordingly.

CONSTRUCTIVE MILEAGE.

This term is usually applied to mileage which the engineman does not actually make, but for which he is paid. As we have seen from the schedule, the engineman is ordinarily paid for 100 miles, even if his run should be only 70 or 80 miles; the amount for which he is paid and which he does not make, is thus a type of constructive mileage, and is strictly unremunerative, as far as the railroad company is concerned. By careful management and adjustment of runs such mileage can be reduced to a minimum, but it requires continuous watching.

There is another kind of constructive mileage, however, which cannot be reduced, and this is the allowance of a greater mileage in the pay than actually exists between the points. For instance, terminals A and B may be 130 miles apart, but the run may be counted as 150 miles and paid for on this basis. This will be understood as actually raising the rate of pay for such portions of the road, and it usually applies to heavy grades or difficult parts of road, where the engine works harder if the men do not. On large systems it is sometimes considered desirable to have a standard rate of pay per 100 miles, and the method of constructive mileage allows a higher rate to be paid on certain designated parts of the road.

As an example of constructive mileage, we give below the actual distances and the allowed distances on one of the western lines:

		Mileage Actual.	Mileage Constructive.
Section	1	92	100
"	2	115	129
"	3	143	159
"	4	23	29
"	5	28	30
"	6	51	59
"	7	149	153
"	8	167	170
"	9	69	77
"	10	46	53
"	11	23	24
"	12	82	100
"	13	50	51

It will be seen that this plays an important part in the cost of transportation. It sometimes occurs that hills must be doubled—that is, the train is heavier than can be taken up by the engine in one train, so it is cut in two—part is taken to the top and the engine then returns to the foot of the grade and brings up the remainder, when they are again united and taken to destination. This may occur because the engine has been overloaded, or because it is not in prime condition and cannot haul the regular load, or again, the profile of the division may be such as to make this an economical proceeding. The writer has in mind a division with easy grades, except at one point, where there was a heavy grade for a few miles. The traffic did not warrant maintaining helpers at this point, so the hill was doubled regularly. It is generally customary to pay for the mileage, which in a case of this kind is really run, and if the hill were five miles long there would be ten miles added to the actual length of the division for such a trip. A southern road contains this clause in its rules: "If at any time engines are unable to handle their rating, and have to double, they will be allowed ten miles for each double, unless this distance is exceeded, when actual mileage will be allowed." Another road allows one hour's time at hourly rates for each double, provided the doubling is not attributable to any

fault of the engineman. It will be seen from this that there are different methods in vogue for settling these various points in the several sections of this country, but in all cases the effect is to increase the cost of operation per ton-mile, with apparently no return to the company.

LIGHT ENGINE MILEAGE.

It frequently happens that, owing to an excess of traffic in one direction, or heavier grades going one way, that the power becomes congested at one end of a division, and empty engines must be sent back to the other end, where there is a greater demand for them. This is a costly and unremunerative service, as it requires not only engineman and fireman, but also fuel, water and oil, and adds a proportion to the repair costs, while there is no transportation of chargeable commodity. As a rule, enginemen are paid reduced rates for such mileage; thus, one road states that enginemen running light will be paid passenger rates, as per class of engine, and as these are usually less than freight rates, there is a reduced pay, if it happen to be a freight engine, as is generally the case. However, in contradistinction to this, we find some rules that say the pay will be according to the class of train over each district. This is somewhat ambiguous, as there is really no train, but it is evidently meant that a freight engine will entitle the engineman to freight rates.

Sometimes we see a heavy freight train sent out with one engine, and either preceding or following it a light engine is sent in the same direction. It might in this case save the wages of a train crew, but frequently this crew must be moved also. It would be more economical to either split the train, or at least double head, as the fuel economy would be greater and the train reach its destination quicker. Of course, if the light engine leads, it can make better time than the loaded one, but there may be such traffic conditions existing that little will be gained

by the light engine. The real object of such an arrangement often is to make an apparent record for heavy tonnage per train-mile, or per loaded engine-mile, regardless of cost.

POOLING.

Something should perhaps be said here on the subject of pooling. While it does not ordinarily affect the cost of operation, as far as the pay of the crew is concerned, it doubtless has an effect upon some of the other lines of expense. Some of the reports made to the last International Railway Congress (1905) on the subject of pooling were very clear on this item of expense. In the report of Mr. Camille Boell, representing an equipment of 22,000 locomotives, mostly in Central Europe, it is concluded "that the pooling system always leads to a very perceptible increase in the expense per mile, and therefore it ought not to be employed, except in case of absolute necessity." Only one of the roads included in the report uses the system exclusively, the St. Gothard, of Switzerland, it having been in force on this road since 1888. By comparing the expenses for 1886 and 1889, the following increases have been found:

Fuel	5.5	per cent.
Lubrication	42.0	"
Maintenance	11.6	"

Other causes have no doubt had their influence upon these expenses, notably an increase in the speed of trains and weight of engines, so it is impossible to determine the proportion of these increases due to pooling. While many roads believe there will always be an increase in the above expenses, due to pooling, we at times find those who profess to believe otherwise. There is little doubt, however, that the prevailing impression is that an increase in cost always follows pooling, and that it is a practice that is of benefit during a congestion of traffic, when the

men are not able physically to stand the mileage which the engines can, but which should be abandoned when the normal conditions are restored. Double and treble crewing will often permit the engines to make as much mileage as when in the pools, and with much better satisfaction all around.

EFFECT OF SPEED.

The speed of the train is about the only element which affects the cost of engine running, if by this term we mean "average speed," or miles between terminals divided by time between the same; as loading, stops, switching, etc., affect the speed between terminals, so the cost will be affected, but only because these items alter the speed. Then it is only below certain limits that even the speed affects the cost. We have seen that in most of the schedules for freight engineers the pay is practically by the mile, as long as an average of 10 miles an hour is maintained. If 15, 20 or 30 miles an hour be maintained or averaged between terminals, the pay will be by the mile, providing the run is at least 100 miles, and that constructive mileage does not apply. Therefore, for speed in excess of 10 miles per hour, there is no change in the item of cost. Of course, a difference per ton-mile may be obtained by changing the lading so that the engine can maintain a higher velocity, and as far as loading is concerned, the least cost for enginemen's wages per ton-mile will occur when the locomotive is so loaded that it can just "average" ten miles an hour over the road.

When the speed is less than ten miles, however, the effect on this cost is great. Suppose, for instance, a running rate of five miles an hour is the best that can be done, owing to layouts or to too much tonnage. If the distance be 100 miles, the trip will consume 20 hours, and the engineman will be entitled to 10 hours' overtime, and

as the usual rate for this is equivalent to 10 miles an hour, he will actually be paid for 200 miles, though running but 100. This is just double the cost per engine or train-mile. Consider what happens, however, if the run is less than 100 miles per day, say 60, for example. At 5 miles an hour 12 hours will be consumed. Overtime will not apply until he has been out 10 hours, as pay is allowed for 100 miles in any case. He will, therefore, be entitled to 100 miles, plus 2 hours' overtime, equivalent to 20 miles, or a total of 120 miles. This is again double rate, as in our last discussion. Now, if the trip had been made at 6 miles an hour, or 10 hours for the trip, or any speed in excess of 6 miles, he would be paid for 100 miles without any overtime, so that the actual rate would be $\frac{10}{6}$, or 66 per cent. increase over the standard rate per mile, due to the constructive mileage on a run of less than 100 miles. Thus we see that the speed limit for changes in cost "per engine-mile" depends on the length of the run, as generally set forth by the various schedules.

CHAPTER XII.

FIREMEN.

This cost is almost identical, in its nature, with that considered in Chapter XI, but the rates are less. We shall exhibit rates for firemen on the roads previously illustrated, and so that these schedules may be identified with those for engineers, will simply affix the letter "f" to the number; thus, schedules "1" for engineers and "1f" for firemen cover the same territory.

Schedule 1 f.

Compensation of firemen in passenger service.

Rate per 100 Miles or Less per Day.

	Districts			
	A.	B.	C.	D.
Eight-wheel locomotives	$2.10	$2.25	$2.25	$2.10
Ten-wheel, less than 50 tons on drivers	2.20	2.35	2.36	2.30
Ten-wheel, more than 50 tons on drivers	2.30	2.45	2.45	2.40
Prairie	2.35	2.50	2.50	2.45
Mogul	2.35	2.50	2.50	2.45
Consolidation, less than 67 tons on drivers	2.30	2.64	2.50	2.45
Consolidation, more than 67 tons on drivers	2.35	2.64	2.50	2.45

Over 100 miles will be paid pro rata.

Schedule 2 f.

Rate per 100 Miles or Less per Day.

	Districts						
	A.	B.	C.	D.	E.	F.	G.
Eight-wheel locomotives	$2.30	$2.30	$2.49	$2.39	$2.39	$2.60	$2.30
Ten-wheel, less than 50 tons on drivers	2.40	2.40	2.60	2.49	2.60	2.60	2.40
Ten-wheel, more than 50 tons on drivers	2.50	2.50	2.70	2.60	2.60	2.60	2.40
Prairie	2.60	3.10	3.10	3.00	3.00	2.60	2.40
Mogul	2.60	3.10	3.10	3.00	3.00	2.60	2.40
Consolidation, less than 67 tons on drivers	2.49	2.49	2.60	2.58	2.58	2.60	2.49
Consolidation, more than 67 tons on drivers	2.60	3.10	3.10	3.00	3.00	2.60	2.58

Over 100 miles will be paid pro rata.

It will be here noticed that the variation is different from what it is in the engineer's schedule. In that, the 8-wheel and light 10-wheel engines paid the same rate throughout—here it is different in all but one instance. Again, schedule 2 allowed the same for all engines on district G; here there are four different rates on this district. Very often a rate is made for a certain class of engine on a district upon which it does not run, this being considered a concession; and while it may appear irregular, it does not really affect the cost. Again, the enginemen and firemen belong to separate organizations, and these matters are usually taken up with them at different times, thus causing inconsistencies in the rates. In a general way it will be noticed that the firemen's pay is, in these schedules, about five-eighths of that for engineers.

On local freights there is an extra allowance of 15 cents per 100 miles. Helper engines entitle the firemen to from $2.53 to $3.10 per day of 12 consecutive hours, with overtime pro rata. If over 100 miles are made within the first 12-hour shift, one-tenth of the daily rate per hour will be paid for the excess, but all work after 12 hours is paid by the hour. These are the rates in mountain territory—on the plains they run from $2.15 to $2.45, depending upon the size of the engine.

In switching service the rate runs from $1.90 to $2.30 per day of 10 hours. If called and not used, 33⅓ miles are allowed, as for the enginemen. These special rules are practically the same as in force for the enginemen.

Schedule 3 f.

Road Service.

Class of Engine.	Passenger.	Freight.	Way-Freight.
Eight-wheel, 18-inch cylinder and under..	$2.25	$2.30	$2.50
Eight-wheel, 19 to 21-inch cylinders......	2.35	2.35	2.50
Atlantic type............................	2.40	2.40	2.70
Ten-wheel, 18 and 19-inch cylinders......	2.50	2.60	2.80
Ten-wheel, 20-inch cylinders.............	2.60	2.75	2.90

These rates are for 100 miles or less, and freight mileage over 100 miles is paid pro rata. Switching service is paid $1.95 and $2, and 2,600 miles per month are guaranteed to all assigned men.

Schedule 4 f.

	Districts					
	Passenger			Freight		
	Mountain.	Undulating.	Level.	Mountain.	Undulating.	Level.
Eight-wheel locomotives	$2.25	$2.10	$2.15	$2.49	$2.45	$2.45
Ten-wheel:						
Less than 50 tons*	2.36	2.25	2.25	2.65	2.58	2.58
More than 50 tons	2.45	2.35	2.35	2.70	2.60	2.60
Prairie	2.50	2.35	2.35	3.10	2.70	2.70
Consolidation:						
Less than 67 tons*	2.50	2.35	2.35	2.85	2.60	2.60
More than 67 tons	2.50	2.35	2.35	3.10	2.70	2.70

These rates are for 100 miles or less per day; all over 100 to be paid pro rata.

Schedule 6 f.

Rates per mile in cents.

Passenger service	1.79 cents.
Through service	2.23 "
Local freight	2.36 "

Runs less than 100 miles are governed by a special list. Short runs are treated the same as for enginemen.

Most of the rates for firemen are about five-eights, or 62 per cent. of the rate for enginmen, except in the last schedule, where they are very little over one-half. The same comments will apply here, on the bearing of these rates to cost of transportation, that were made in Chapter XI. Generally overtime arrangements are the same for firemen as enginemen, being usually equivalent to 10 miles an hour as of the rate and classification on which they are employed. Some roads, however, have a fixed rate, as we found for enginemen in a couple of cases. Thus, on the road in the west, where the engineers

*Weight on drivers.

received 36 and 32½ cents per hour, we find that full-rate firemen are paid 22½ cents per hour and junior firemen (first year) 20 cents. On the eastern road quoted firemen receive 19 cents per hour in passenger service and 22 cents in freight. The methods used in computing overtime are the same as for enginemen.

The other items which were considered in our last chapter, viz.—Delayed Time, Constructive Mileage, Pooling and Effect of Speed—need no further examination here, as the same arguments and considerations will apply as well to the left-hand side of the engine as to the right. For ordinary estimates and statements we can take 1⅝ times the amount paid the enginemen to represent the wages of the engine crew (engineer and fireman) and use the rules and schedules given in the last chapter.

CHAPTER XIII.

HOSTLING AND TURNING.

It is customary in this country for enginemen of incoming trains to leave their locomotives on some designated standing track, where the "hostler" or "engine despatcher" takes it and places it successively by the coal trestle and water tank or stand-pipe, filling up the tender, the ash-pit, to have fire cleaned, and over the turntable and into the roundhouse. This proceeding may be modified in some cases, but in general it follows the above schedule. In taking engines out of the house, in some cases this is done by the enginemen; and in others by hostlers; passenger locomotives, having definite leaving times, are more usually taken out by their own crews.

In many cases the wages of hostlers go into a general account of "roundhouse labor," which includes wiping, inspection and various other small charges. The *Railroad Gazette* of Feb. 19, 1904, however, gave considerable data on the various details of roundhouse charges, from which we gathered the following points:

Cost of Hostling per Engine.

An Eastern railroad, from	39 to 54 cents.
A Southern railroad, from	15 to 78 "
A Western railroad, averaged	33 "
Another Western railroad, averaged	80 "

There is a great variation in these figures, no doubt depending largely upon the conditions existing at different points, and the number of engines cared for. As an average, however, we would expect 50 cents to cover the cost of "hostling" a locomotive.

The cost of turning depends upon the facilities with which the terminal is equipped. If the table be operated by hand, as in days (mostly) gone by, the question of balancing and friction of the table under load will be of great importance. It has been no uncommon thing to see four or even eight men pulling around an engine of great weight upon an old table, too weak for the load and too short to permit the locomotive to be balanced upon it. When this is the case (and it too often is) it is usual to call out the wipers and as often as an engine must be turned these men drop their other duties and man the bar. The exact cost of such an operation must depend entirely upon the number of engines turned a day, and the size of the gang necessary to move the table.

On the other hand, turntables equipped with motors are very expeditious and save time as well as labor. As a rule, one man is continually on duty to manipulate the table, and when the number turned is very large, requiring rapid work, a helper is sometimes employed to "spot" the engines. At the Chicago avenue roundhouse of the C. & N.-W. Ry. as many as 400 engines are turned a day, many not passing into the house, but merely turning for suburban work. It formerly required four men continually on this table, but the application of an electric motor disposed of this gang and turned the engines in less than one-quarter the time. In fact, the motor handled the engines with so much ease that at one time, when repairs were necessary, a gang of eight men were put on the table in order not to delay the turning of the locomotives, as the motor had set a pace which the four men previously used could not maintain.

There have been various reports on the cost of turning locomotives by hand and power made at different times to the railroad associations. It is generally conceded that the power turning is cheaper if the number of

engines turned is large. The cost of installing a steam, electric or gasolene motor has been stated to run between $1,000 and $1,200, providing that electric current is available; if a dynamo and engine must be purchased for this work it will double the above cost. The Tatlow motor, operated by air from the compressed supply of the locomotive on the table, will cost only about half as much, but if there is no engine on the table, or if the engine be "dead," the table must be turned by hand.

The cost of turning locomotives by power at six points on the Lehigh Valley for one year was reported as follows:

	Horse power.	Engines per day.	Average cost— Per day.	Per engine.
Gasolene motor.........	5	170	$3.78	2.22 cts.
" "	5	110	3.40	3.09 "
" "	5	194	3.55	1.83 "
" "	5	121	3.41	2.90 "
" "	5	46	2.91	6.50 "
Electric motor..........	20	140	3.99	2.85 "

This shows the cost fairly constant per day at about $3.50. If only 50 engines are turned it will amount to about 7 cents an engine—if 200 be turned less than 2 cents. Where hand power is used, and, say, three men are required, the cost would probably be 4 or 5 cents per engine, assuming that these men are otherwise employed between turning. It would probably not pay to install a power outfit on less than 50 locomotives turned in 24 hours; for 75 or more there is little doubt as to the advisability of such an expenditure. Where more than one man is constantly employed on this work, to the exclusion of other duties, it will be a paying investment.

The estimated costs of operation per day of 24 hours, based on turning 250 engines, was given by a committee as below:

Electric motor (without special dynamo)..........	$3.92
Steam engine....................................	4.40
Gasolene motor..................................	3.95

These figures include labor, fuel or current, supplies and repairs, but not interest and depreciation.

From the data given above it should be a simple matter for any one to estimate approximately the amount which it is costing to turn engines at a given point by knowing the conditions existing at that locality.

CHAPTER XIV.

CLEANING FIRES.

This cost will depend not only upon strictly local conditions and the price of labor, but the quality of the fuel used. With coals that burn to a free ash, the cleaning of the fires will be confined to shaking the grate bars and hoeing out the ash-pan—if the latter has drop bottoms or hoppers the process is extremely simple and brief. On the other hand, engines sometimes come in so badly clinkered that it may require a couple of hours to properly clean the fire-box of slag and incombustible masses. This may not apply to all the engines coming in from their runs, for it is often claimed that by having two cleaning tracks, if an engine arrives in the condition above mentioned, the other engines giving less trouble can run around the difficult member, thus facilitating the work of turning. The process of cleaning is managed differently at various points. In some cases the hostler shakes or drops the fire into the ash-pan, while the ash-pit man pulls it out of the pan; in others a "fire-knocker" is employed to break up the clinker and push it into the pan. Occasionally, but not often, the pit man does this work, but the precise method depends upon the nature of the coal and the number of engines to be handled. Then, at times, the smoke-box must be cleaned of cinders, which may provide another operation. After this work has been done and the engine moved on into the house the ashes must be taken from the pit.

This brings us to the construction of the pit itself. The old style were merely "pits," and all the refuse had to be thrown out over the rail and into a car on a depressed track alongside. A more advantageous arrangement is

the "elevated pit," where the ashes are simply raked out under the rail while the engine is still on the "pit," or is moving off and pushed or thrown into the loading car without having to be actually lifted to any distance.

Then there are mechanical arrangements which lift buckets out of the pit and drop their contents into open cars, or elevate the ashes by an endless chain of buckets and place them in a bin, where they drop by gravity into cars, or take them at once to the waiting cars. This all varies the cost of cleaning fires, as the expense does not cease until the refuse is actually deposited at some point, though as there is generally demand for material for filling, and the hauling will benefit this work, the expense, as far as the engine is concerned, may be considered ended when the cars are loaded from the ash-pit.

It is likely that under average conditions one-half hour will be consumed by engines at the ash-pit, during most of which time two men will be engaged upon cleaning the fire and front end. If these men are paid 15 cents an hour, we will have the cost of such cleaning represented by this sum, viz.—15 cents. In many cases the cost will be greater, in others less, so that the average will probably not be far from the figure stated. There may be so few engines that one man will not find his time wholly occupied with pit work, but it is then customary to provide him with other duties. If many engines arrive more men and facilities are needed, and mechanical devices in this line are more generally for the purpose of increasing the output than for diminishing the cost of cleaning fires.

CHAPTER XV.

WIPING.

This item is an exceedingly variable one, and it must be considered in connection with the local existing conditions. The practices in the method as well as in the amount are, perhaps, not alike on any two roads. Some of our most important railroads do little, if any, wiping of freight locomotives and not much of passenger engines. Even limited trains are sent out with locomotives that resemble mud balls, and the shape is all that distinguishes them as a piece of machinery. This is somewhat exaggerated, but filthy locomotives are too often the order of the day.

There are several reasons for this, and they are not hard to trace. When engines were small and were regularly assigned to crews, it was the duty of the fireman to keep the locomotive clean, and even to polish the brass work, of which there was a great amount. As the size and quantity of power increased, there was a marked tendency to reduce brass work and polished surfaces of all kinds. This was the first reduction of the fireman's labors. As the engines still kept growing, and more surface had to be cleaned, the fireman's wiping was confined to the portion above the running board, and then to the inside and outside of the cab. Recently a number of roads have discontinued the practice of requiring the firemen to do any wiping on pooled engines, and also those of large sizes in assigned service, the men claiming (with some justice) that they did not have time to celan engines and obtain the necessary rest during lay-overs. When the wiping was done by the firemen there were no extra

expenses attached, except the quantity of waste and cleaning mixtures used, which would, altogether, probably not amount to over 10 or 15 cents per engine cleaned. But now, when men have to be employed specifically for this purpose, the figure has increased, and in an effort to keep down the cost comparatively little wiping is done.

The actual cost depends, of course, upon the price of labor, speed of workmen and quality of work. The costs are variously stated at from 10 cents to $2 an engine, so that little data can be obtained from such reports that could be used with any satisfaction. The writer calls to mind one road with which he was connected, where the wiping was done by piecework. A contract was made with a gang leader to clean all the engines entering the house for 50 cents each, and he hired the necessary men and looked after them. These were mostly passenger locomotives, the largest having 20-in. cylinders, of the 4-4-0 type. The firemen were supposed (at that time) to clean above the running board, and the wipers took the wheels, pilots, front ends, tenders, trucks, etc., and the work was very well done—better, perhaps, than actually needed. Later this road relieved the firemen from all wiping.

We do not believe that satisfactory work of this kind can be done for less than 50 cents an engine, and very large ones will cost more. It would certainly require from three to five hours to do the work properly. Under the arrangement above mentioned each man averaged three or four engines per day, so that fairly good wages were made at the work.

The writer has always favored clean engines, not for the benefit of appearance alone (although that has a certain commercial value), but for the greater opportunity of discovering defects that might later cause breakdowns on the road. With half an inch of mud on wheels, boxes, eccentrics, etc., it is almost impossible to discover incip-

ient cracks, and if the wipers are careful they can prevent many an engine failure on the road. Indeed, some roads pay the wipers a bonus for discovering and reporting cracks, etc., and other roads promise promotion to the much-coveted fireman's berth for careful examination and reporting of defects. Wiping not only furnishes a certain amount of inspection, but it greatly facilitates the work of the regular inspector, who is ordinarily paid better wages than the wipers.

CHAPTER XVI.

INSPECTING.

This item is about as irregular as the one last considered, and depends largely, if not entirely, upon the method of handling the engines. Where assigned crews and engines operate, few inspectors will be found, as the engineer is supposed to do his own inspecting—in fact, he can hardly oil and look after the machinery day in and day out without knowing the condition of the engine in detail. It is true that enginemen seldom know the link motion parts thoroughly, and there is some excuse for this. When engines arrive from a trip they generally lie upon the "standing track" for an indefinite time, and the enginemen dislike to "worm" themselves between the wheels and the track, perhaps thick with mud, soil their over-clothes, and generally inconvenience themselves, instead of going to their homes. Some roads have built inspection pits, so that a man can easily get under the engine and examine all parts of the machinery, and these are very much to be commended, though somewhat costly. It is a generally accepted proposition nowadays that if we wish a piece of work satisfactorily done we must make it convenient for those who do the work.

When the inspection is performed by the enginemen there is no charge made for this work, and it practically costs the company nothing. When engines are pooled, however, one of the first industries to be organized is the inspection force, and few, if any, roads attempt to pool locomotives without having regular inspectors appointed. This is not so much with the idea of relieving the enginemen, as they are expected to report anything wrong on arrival, but it checks them up, makes them more attentive

to this work and gives some assurance that the engine is in proper condition for the succeeding crew. When engines are assigned the engineman will naturally watch for defects so as to protect himself against failures on future trips, but when he may never see the engine again his main object is to get in from the current trip and let the next man look out for trouble.

The cost of inspection, when done by special inspectors, varies considerably. It is often the custom to take some engineman who has been disqualified from road service on account of some physical misfortune, and give him the post of inspector. As he will expect to make somewhere near running wages, the cost of the work is apt to be too high. Sometimes a machinist is put on this work, and obtains machinist's pay, which may be nearly as great as that of enginemen. Very often bright young men are selected, with promises of promotion, if their work is well done, and in these cases the pay is much lower.

The length of time taken will depend upon the man—some will claim that they can inspect an engine in 15 minutes, but if it be done thoroughly, as it should to be effective, it will take about double that mentioned. Some roads do this piecework, paying 10 cents for each engine inspected, but we believe a nearer figure will be 15 cents for the average case, where a special man or force is employed for this purpose.

CHAPTER XVII.

FIRING UP AND CALLING.

Firing up is done in a variety of ways. The old method was to use wood—scrap or cord-wood, as was available, and even to this day we see piles of fire-wood about the roundhouses. A common allowance was one-eighth of a cord to a fire, and if wood costs $2.50 a cord, which is a common price in some localities, the material used would represent about 30 cents.

Fuel oil is quite a favorite method nowadays, and reports are made which indicate a very low cost (about 3 cents per fire), but as a matter of fact, the oil is used to ignite the coal, and we may not obtain the same heating effects as with the wood, and it is only proper to charge an amount of coal that, with the oil, would equal the heat of the wood. It is often an advantage, moreover, to obtain wood ashes on the grate, as with some coals the oil blast has a tendency to fuse them and form a clinker on the grate bars. The amount of coal used in addition to the wood or oil has been given as low as 500 lbs. and as high as 1,500 lbs., as much depends upon the size of engine, etc.

The cost of the fuel has already been discussed, therefore the labor will be considered here only. The question of firing up engines in a roundhouse is of much importance and must be done by a careful man—boilers have been ruined by incompetent hands building a fire in a boiler that contained no water. After the fire has been lighted the engine must be watched until taken from the house, and the attendant must see that the water level is maintained, and that the boiler is not allowed to blow off. One fire builder can attend to a roundhouse turning per-

haps 40 engines in 24 hours; that would be 20 fires to start during his watch, or about half an hour's attention per locomotive, and as such men are paid low wages the labor would probably amount to 10 cents for each fire started. The exact amount will depend on the detail arrangements, but the amount is such a small proportion of our operating expenses that it will hardly pay to discuss it further.

Calling is generally performed by boys or young men. The former earn about $15 a month—sometimes $20, and they are usually expected to possess a bicycle. If a call takes 15 minutes, as two men must be summoned for each engine, there would be a total time needed of one-half hour per engine, so that the cost of such work should not run over 3 or 4 cents to each locomotive despatched. Between calls the boys do office work, so that the actual expense is trifling.

HANDLING.

It is usual to group the various items considered in the last articles under the general term "Handling Locomotives," by which is meant the various duties performed during their stay at a terminal, exclusive of repairs. Sometimes the labor of the coal chute attendants is included, and also of boiler washers, but these are actually chargeable to the fuel and water accounts; but although the former is frequently so charged the latter seldom is treated in this manner.

If we summarize the different items in accordance with our review we find as follows:

Hostling	50	cents per engine.
Turning	5	" " "
Cleaning fires	15	" " "
Wiping	50	" " "
Inspecting	15	" " "
Firing up	10	" " "
Calling	5	" " "
Total	$1.50	

Inspection of a number of performance sheets of several prominent roads, both eastern and western, shows an average of about 1.3 cents per mile for the different roads. The average mileage per month is perhaps 3,600, which would mean 120 miles a day, and assuming that each engine would reach a terminal once a day we have $120 \times 1.3 = \$1.56$ as the costs, which compares closely with the estimate of $1.50 given above.

The statement of costs found in the *Railroad Gazette* of Feb. 19, 1904, indicates a wide variation—from 13 cents to $1.80. It is evident that the first figure is worthless. The average for the items enumerated above and for 11 roads reported in the article mentioned is $1.36 per engine. If washing out is frequent and is also charged to this account, as well as the labor on coal trestles, then the total will probably be nearer $2 an engine than $1.50. Under any circumstances the variation, considered as a percentage of the total cost of operation, will be insignificant, but even this discrepancy can be reduced if we know the conditions existing at the terminal point and make corrections accordingly.

It will be noticed at once that these several items comprised in the general term "handling" are all practically independent of either the distance traveled, the speed attained, or the load hauled, unless the run is so short that cleaning fires and wiping are eliminated, as in the case of brief turn-around trips. Otherwise the cost, of terminal expenses is a definite one, and would be as heavy for an engine which had made a 100-mile trip as for another which may have run twice that distance. This leads us at once to the proposition that we cannot decrease these charges by any variation in speed or train load, but by making a greater mileage or a longer trip between terminals these items may be reduced on a mileage or a ton-mileage basis.

For some years it was customary to divide a road

up into engine divisions of about 100 miles each; nowadays the tendency is to increase this to 150 or 200 miles. There is a limit to the length, in that the freight trains may not be able to cover it in sufficient time so as not to exhaust the crews. The writer has known of 200-mile divisions that have required over 40 hours for their traverse, which is very excessive. If 12 miles an hour be maintained between terminals (including lay-outs) it will require 12 to 13 hours to make a trip of 150 miles under ordinary conditions, and if unusual delays occur, this will easily extend to 16 or 18 hours, which is quite long enough—too long, in fact—for men to stay continuously on duty. With a double-track road, and not too much passenger traffic to clear, 200 miles can be handled to good advantage, but with single track it is likely that 150 miles is about the maximum length that it would be wise to use for engine divisions in freight service. Passenger runs can be considerably longer, and are often arranged to cover two freight divisions.

CHAPTER XVIII.

APPLICATIONS.

The application of the foregoing to actual practice is, of course, the important result for which this study has been undertaken, and in order to make this clear a number of hypothetical cases will be worked out, so as to fully illustrate the method of procedure under different circumstances.

Let us see how the investigation will generally be brought to a start. A division of a road exists with a certain combination of grades and levels, curves and tangents. To handle the traffic over this division a number of locomotives have been provided of definite type or types. There is probably (at least at times) all the freight that can be comfortably hauled by the number of locomotives assigned to that division. The problem, then, that confronts the transportation official is two-fold: To haul the freight at a minimum cost and to obtain the maximum amount of work every month (or week) out of each locomotive in working order. It may be that in working for one result, say low cost, the maximum ton-miles may not be gotten out of the engine; then it will depend upon the amount of business offered whether it is most desirable to haul more freight at a higher cost or less at a reduced cost. In times of traffic congestion there is no hesitation in accepting the first alternative. But, as will be shown, it may sometimes happen that not only a low cost per ton-mile, but a high monthly movement per engine can be obtained by judiciously fixing train loads and speeds, and when this is possible of accomplishment we have obtained the schedule of maximum efficiency, both as to cost and quantity of traffic moved.

As may be expected, the computations necessary for analyzing this subject are lengthy and complicated, but there is so much to be gained by a proper knowledge and observance of the laws involved that it is well worth the amount of study required. It is evident that there may be any number of operating divisions differing one from the other, and a variety of engines may be placed upon them, so that it would be impossible to present more than a few typical cases. We shall therefore assume certain profiles and consider that they are operated by locomotives of a uniform standard, and it will be clear from what has gone before that any combination may be worked out in a similar manner.

UP-GRADE WORK.

In order to study the effect of speed and loads on up-grade work, let us consider a division 150 miles long and uniformly graded to 1 per cent. We will at present study traffic only one way—that is, up-hill—as returning an engine could take almost any train load within reason. We will assume that the division is equipped with the size of consolidation engines used in developing, Figs. 1 to 10 weighing 150 tons with tender, and having an available tractive force of 40,000 lbs. As freight trains are ordinarily run at speeds of less than 30 miles an hour, we will study the results at five miles and multiples of 5 up to 30 miles per hour. Table A (on page 169) gives six columns (besides the data headings) for values from 5 to 30 miles, and line one indicates the speed considered. Line two gives the weight of train in tons, back of tender, and is the maximum that the engine can take on a 1 per cent. grade at the speeds indicated. These weights are obtained by superimposing Fig. 8 on Fig. 2 (as has been already explained in connection with these diagrams), and noticing where the intersection of speed lines and curve b c are projected

on Fig. 8. Thus we see that while 1,450 tons could be hauled at five miles an hour, only 400 could be taken at 30 miles. (It is necessary to draw additional curves on Fig. 8 below the 1,000-ton curve, but this is readily done by the help of formulæ 4 and 6.)

Line three gives the ton-miles per trip, back of tender, and is simply the weight of trains multiplied by 150, the division length in miles, thus $1,450 \times 150 = 217,500$ ton-miles. Line four denotes the running time, or 150 divided by the running speed, as in the five-mile column $\frac{150}{5} = 30$ hours. There will always be delays, however, and we have assumed that these will amount to 20 per cent. of the running time, so that line five, the actual time between terminals, is 20 per cent. in excess of line four. Thus, $30 \times 1.20 = 36$ hours.

Now, by dividing the distance 150 miles by this latter figure, we obtain the average speed between terminals, shown in line six; as for instance $\frac{150}{36} = 4.2$ miles per hour. Line seven indicates the amount of coal burned per mile for the weight of train and speed given in lines one and two. These values are obtained from Figs. 2 and 8, as explained in the chapter on fuel, being read directly from the diagrams. It will be noticed that at 10 miles an hour 800 lbs. may be burned per mile, while at lower and higher speeds the value is less. This, of course, assumes that the maximum loads for the different speeds are taken. The coal burned per trip, line eight, is simply the product of line seven, and the distance, thus $500 \times 150 = 75,000$ lbs. of coal.

In the chapter on water we found that we could ordinarily consider the quantity of water in gallons used by a locomotive as three-quarters of the amount of coal burned in pounds, or a consumption of three-quarters of a gallon for every pound of coal. Line nine therefore is uniformly

three-fourths of line eight. For example, $75{,}000 \times \frac{3}{4} =$ 56,000 gal. approximately.

We have now obtained the quantities of coal and water for each trip, and can commence to insert cost values. Line ten gives the cost of coal per trip, and we will first allow a price of \$1 per ton of 2,000 lbs. Thus the first figure in line eight being 75,000 lbs., or $\frac{75{,}000}{2{,}000} =$ 37.5 tons, represents a value of \$37.50, and the other values follow in the same manner. We can take water at 10 cents per 1,000 gallons and figure the amounts for line 11. For instance, 56,000 gal. will be worth \$5.60.

When we come to the cost of lubrication we must refer to the chapter on waste. As we are working upon a freight engine with 21-in. cylinders, the cost of lubrication may be expected to run about \$3.06 per 1,000 engine-miles. This gives us $3.06 \times .150 = .50$, or 50 cents per trip. Under our discussion of this subject it was considered that this cost was affected very slightly by the train load and speed (within moderate limits), so that the amount of 50 cents will apply to the several columns selected for line 12.

The cost of supplies (line 13) was stated to approximate 20 cents per trip, which accounts for that value being set in all columns.

Line 14, cost of repairs, is figured on the "Tractive Force Tons Per Mile." From Fig. 8, at the intersection of the load curves and the speed lines, we find the resistance of the train, including the engine and tender. As this corresponds to the tractive force needed, we obtain directly the required figure. For instance, 1,450 tons at five miles an hour (including 150 ton engine and tender) on a 1 per cent. grade require a tractive force of 40,000 lbs., or 20 tons. The allowance (from chapter on repairs) was to be 1 cent per ton tractive force per mile plus 1 cent per engine mile. As the grade is uniform (in

the case being considered) there will be 20 tons exerted throughout the trip and we shall have 20 ton-miles + 1 engine-mile, or $20 + 1 = 21$ cents per mile run, and for 150 miles, $.21 \times 150 = \$31.50$ for repairs, including general and running repairs. The other values of line 14 are obtained in the same manner. Thus, at 25 miles an hour the maximum available tractive force (see Fig. 2) is 20,000 lbs., or 10 tons. So $10 + 1 = 11$ cents and $.11 \times 150 = \$16.50$, representing the value of repairs for this trip.

Allowance for renewals (line 15) must be taken more or less arbitrarily, and as we previously proposed 1 cent per engine mile, we have figured this item at $1.50 per trip of 150 miles for all the speeds considered.

Line 16, pay of engineer and fireman, must be taken from our schedules for this item. If we use schedules 3 and 3f we find for this size engine in freight service a rate for enginemen of $4.25 per 100 miles and for firemen $2.75, a total of $7 for 100 miles or less. The overtime rate is at 10 miles an hour, and as the average speed of the five-mile an hour run is only 4.2 miles per hour the whole 36 hours occupied will be figured at overtime rates, or 70 cents an hour, so that $36 \times 70 = \$25.20$. At 10 miles per hour (8.3 average speed) we obtain $18 \times .70 = \$12.60$ for the trip, but at higher speeds the rate is uniformly on the mileage basis (as the average speed exceeds 10 miles an hour), or $1.50 \times 7.00 = \$10.50$.

For cost of handling at terminals we found that, including hostling, turning, wiping, inspecting, cleaning fires, firing up and calling the expense would run about $1.50 per turn, and if we allow 50 cents more for washing out and coaling we can fill out line 17 by inserting $2 in each column. Line 18 covers the interest allowance, and is deduced as follows: A locomotive, such as we have selected, will cost in the neighborhood of $18,000, and at 5 per cent. will represent an annual charge of $900. The rate per day is therefore $\frac{900}{360} = \$2.50$, or say, 10 cents per

hour. This charge goes on whether the engine is on the road or in the house, and if we assume that five hours are needed for turning and running repairs, we get a total for the trip and lay-over of $36 + 5 = 41$ hours, and at 10 cents an hour the amount is 4.10. So for the other speeds—at 30 miles an hour, or six hours actual time on the road, we have $6 + 5 = 11$, or $1.10.

We now have all the charges entering into the cost of operating the locomotive over our typical division, and by summing the amounts from lines 10 to 18, inclusive, we obtain the "locomotive cost" per trip, line 19. It is interesting here to note that this total cost is a maximum at or about 10 miles an hour running time, or 8.3 miles average time on the road, allowing 20 per cent. for delays.

In order to obtain the cost of transportation, however, which is the vital point, we should also include the train supplies, car repairs and pay of trainmen, as these will vary in accordance with our speed and load. The first of these, "train supplies," will depend partly upon the number of cars in the train, though the largest portion will probably depend more upon the "train mileage" than the "car mileage." We can, therefore, assume this figure at 1.5 cents per train mile, and this gives us a uniform value of $2.25 per trip for line 20.

Car repairs (line 21) could, perhaps, be omitted from consideration here, as it is presumed that there is a definite amount of traffic to be handled, and consequently a certain amount of car mileage must be made, but in order to complete the estimate of "train charges" a value will be given to this item. One-half cent a car mile is probably a fair average for cost of repairs, and as the average weight of loaded cars is not far from 33 tons, we have $.5 \div 33 = .015$ cent per ton-mile, or 15 cents for 1,000 ton-miles, which value we shall use in our present discussion. In the first column, then, we have $217.5 \times .15$

$= 32.60$ (about), and so for the other values—the last column giving $60 \times .15 = \$9.00$ per trip.

Line 22 considers the pay of trainmen (back of engine) and assumes the following rates: Freight conductors, \$89.70 per month for 2,600 miles in 26 days; for excess mileage the same rate is allowed, viz.—3.45 cents per mile. Overtime is allowed whenever the speed is less than 10 miles an hour, and is computed at the rate of one mile for each six minutes' overtime. Freight brakemen receive \$59.80 per month of 2,600 miles in 26 days, or 2.3 cents per mile for excess mileage, overtime being arranged in the same way as for conductors.

If a train crew is composed of a conductor and two brakemen (as is usual), the combined rate is $3.45 + 2.3 + 2.3 = 8.05$ cents per mile, or 80.5 cents per hour. As for the enginemen, the first two schedules will be on the hourly basis and the remainder on a mileage basis. Thus, $36 \times .805 = \$28.98$ for the five-mile column, $18 \times .805 = \$14.49$ for the 10-mile and $150 \times .0805 = \$12.08$ for the others, where the average speed exceeds 10 miles an hour.

This completes our tabulation, and by adding the figures in lines 19 to 22, inclusive, we obtain the total transportation cost, as far as the train movement is affected by speed and loading at least, as shown by line 23. Track and superintendence expenses are, of course, omitted, as it would be practically impossible to vary these in proportion to individual train loads and speeds, particularly as a definite ton-mileage (all that is offered) must be transported in any case, and the other expenses will be nearly the same, no matter whether the trains are heavy or light.

By line 23 we find that the greatest cost of train is at five miles an hour running speed, and with the heaviest load, though the cost does not decrease in proportion to the latter.

In line 24 the cost per 1,000 ton-miles (back of ten-

der) is obtained by dividing line 23 by line 3, thus $\frac{171.93}{217.5}$ $= .79$ (approximately). This line is of great interest, as it gives the best basis for comparison of costs. It will be observed, however, that it includes the weight of cars, and only covers the operating expenses as noted in the several headings. The total expenses will be nearly three times as great, and if the loading and cars are of equal weight the total cost per revenue ton-mile will be five or six times as much as shown. But we are here considering the cost of the actual movement of gross tonnage back of the tender. Examination of line 24 indicates that for the conditions assumed the lowest cost is obtained at 15 miles an hour, though the lower speeds are only slightly greater in cost. As the speed is increased, however, above 15 miles, the expense goes up rapidly, and at 30 miles it is 50 per cent. more than 5 to 15 miles per hour. Thus we see why stock and fast freight trains are so much more costly to move than ordinary slow or dead freights, largely owing to the fact that the crews are paid by the mile at high speeds, and the weight of train is reduced to permit the engine to attain the desired velocity. At very slow speeds the hourly rate comes into the calculations and again runs up the cost.

While line 25 is not entirely rational, it is of a good deal of interest. By not being rational we mean that a division of 1 per cent. up grade in one direction would necessarily return its engines down hill, and they could take heavy trains and make high speeds without being dependent upon the power of the locomotive. The values given in this line have been obtained by dividing the number of hours in a month of 30 days (720 hours) by the hours needed for a trip and lay-over, in order to get the trips per month that could be made on the schedule considered, and multiplying by line 3 the ton-miles per trip and dividing, of course, by 1,000,000. Thus, for column

TABLE A.—*Maximum Loads, 150 Miles of 1 Per Cent. Grade.*

1. Running speed, miles per hour	5	10	15	20	25	30
2. Weight of train, tons back of tender	1,450	1,430	1,100	800	560	400
3. Ton-miles per trip, back of tender	217,500	214,500	165,000	120,000	84,000	60,000
4. Running time, hours between terminals	30	15	10	7.5	6	5
5. Actual time, hours between terminals	36	18	12	9	7.2	6
6. Average speed between terminals	4.2	8.3	12.5	16.7	20.8	25
7. Coal burned, pounds per mile	500	800	540	400	320	250
8. Coal burned, pounds per trip	75,000	120,000	81,000	60,000	48,000	37,500
9. Water used, gallons per trip	56,000	90,000	61,000	45,000	36,000	28,000
10. Cost of coal, per trip	$37.50	$60.00	$40.50	$30.00	$24.00	$18.75
11. Cost of water, per trip	5.60	9.00	6.10	4.50	3.60	2.80
12. Cost of lubrication, per trip	.50	.50	.50	.50	.50	.50
13. Cost of supplies, per trip	.20	.20	.20	.20	.20	.20
14. Cost of repairs, per trip	31.50	31.50	26.25	20.20	16.50	14.25
15. Allowance for renewals, per trip	1.50	1.50	1.50	1.50	1.50	1.50
16. Pay of enginemen, per trip	25.20	12.60	10.50	10.50	10.50	10.50
17. Cost of handling, per trip	2.00	2.00	2.00	2.00	2.00	2.00
18. Interest allowance, per trip	4.10	2.30	1.70	1.40	1.22	1.10
19. Locomotive cost per trip	108.10	119.60	89.25	70.80	60.02	51.60
20. Cost of train supplies, per trip	2.25	2.25	2.25	2.25	2.25	2.25
21. Cost of car repairs, per trip	32.60	32.10	24.80	18.00	12.60	9.00
22. Pay of trainmen, per trip	28.98	14.49	12.08	12.08	12.08	12.08
23. Cost of movement, per trip	171.93	168.44	128.38	103.13	86.95	74.93
24. Cost per 1,000 ton-miles, net	.79	.79	.78	.86	1.03	1.25
25. Million ton-miles, per engine, per month	3.82	6.70	6.98	6.18	4.96	3.92

under five miles an hour we have $\frac{720}{41} \times \frac{217,500}{1,000,000} = 3.82$ million ton-miles per engine per month, and it is evident that this merely indicates the "rate" of doing work while ascending the grade—the down-hill movement would alter these figures very considerably. Still, as we are considering up-hill traffic only, it is interesting to compare the various rates of producing ton-mileage. The most important point to notice is that at 15 miles an hour running time (12.5 miles average speed) we are able to produce the greatest amount of transportation per engine in service, and this is also the schedule for minimum cost. Under the conditions which have been assumed, therefore, if we run at 15 miles an hour, we not only do the work cheapest, but get the most of it done.

It will also be observed that while a running schedule of five miles an hour will maintain the cost of transportation at practically the same figure, but little more than half the transportation will be produced, and that with long hours and tired-out crews, whereas the 15-mile schedule will bring the trains to the end of their runs in good time.

It must not be taken for granted that this condition will obtain for all combinations of cost, pay and profiles, but it is significant that actual tests on several important roads have confirmed these figures. (Later we will estimate other profiles in order to compare the results.)

In the *American Engineer* of April, 1904, Mr. G. J. Bury, General Superintendent of the Canadian Pacific, is quoted as saying: "If freight trains average 15 miles an hour, train and enginemen can make 5,000 miles a month, while if the average be reduced to eight miles an hour, the men cannot stand more than 3,000 miles a month. Sixty crews at 15 miles an hour will make 300,000 train-miles per month, while at an average of eight miles an hour it will take 40 more crews, or 200 extra men, to handle that business.

"Looking at the matter from a financial standpoint, a consolidation engine hauls a train weighing 1,100 tons (tare and contents) over 118 miles in a district where there are several grades of 1 per cent.; taking into consideration the time for meeting trains and letting faster trains pass, slowing up over grades, etc., it averages eight miles an hour, the cost being as below:

Wages, engineman and fireman	$6.90
Overtime for engineman and fireman	1.75
Wages, conductor and brakemen	7.73
Overtime, conductor and brakemen	2.88
Oil and waste for locomotive	.30
Fuel (7 tons at $3.20)	22.40
Total	$41.96

or 32.3 cents per 1,000 ton-miles.

"The same train, if loaded with 1,000 tons, averages 15 miles an hour over the same district, and the cost is as follows:

Wages, engineman and fireman	$6.90
Wages, conductor and brakemen	7.73
Oil and waste for locomotive	.30
Fuel (6 tons at $3.20)	19.20
Total	$34.13

or 28.8 cents per 1,000 ton-miles.

"In a general way locomotives should be so loaded when traffic is dense that they will make an average speed of 15 miles an hour, providing there are no unusual delays."

As indicated by table A, if we run above 15 miles per hour, we also reduce our earning capacity and increase our cost per ton-mile. In order to observe the effect of higher-priced coal, we have calculated the cost at $2 per ton, the other figures remaining as before. We now obtain as follows:

TABLE B.

Running speed	5	10	15	20	25	30
Cost per 1,000 ton-miles	0.96	1.06	1.02	1.11	1.32	1.56

Here the speed of five miles an hour shows the low-

est cost; but 15 miles gives the next higher rate, and when we consider that the movement and consequently the earning power of the engine per month are nearly doubled, there is little doubt as to the 15-mile policy even under these new conditions.

Tables A and B give the cost per 1,000 ton-miles and the number of million ton-miles per engine per month on a 1 per cent. grade of 150 miles in length, when the maximum possible loads are taken at the speeds selected. But if these loads can be hauled we can obviously take lighter ones at these speeds, and we should know how this will affect the cost and quantity of transportation. Let us determine which values composing the cost will be modified by reducing the train load. It is evident that the quantity of coal and water used will be less, and also that the repair account will be diminished, so that items 10, 11 and 14 will be reduced. As less cars will be in the train, item 21—car repairs—will also diminish. Items 12, 13, 15, 16, 17, 18, 20 and 22 will remain constant for each speed, regardless of the train, in accordance with our assumption, as they are based upon engine miles, trips or hours required for the run. Table C shows how the values are computed for five miles an hour.

Line 3 evidently follows from 2 and the distance—150 miles—being the product as before. Line 7 is found by Figs. 2 and 8, as before, but it was necessary to draw upon Fig. 8 additional lines representing the resistance of trains under 1,000 tons weight, and line 8 simply multiplied these figures by 150. The water (line 9) allowed three-quarters of a gallon for each pound of coal, as previously. Line 10 was based on line 8 at $1 per ton, and line 11 on line 9 at 10 cents per 1,000 gallons. Lines 12 and 13 are the same as previously shown in Table A. Line 14 was based on tractive forces of 19, 17, 14.5, 12, 9.5 and 7 tons, respectively, as determined from Fig. 8, and the additional lines for loads less than 1,000 tons.

Lines 15, 16, 17, 18 and 20 are simply reproduced

Reduced Loads.] TABLE C. [5 Miles per Hour.

2. Weight of train, tons back of tender	1,400	1,200	1,000	800	600	400
3. Ton-miles per trip, back of tender	210,000	180,000	150,000	120,000	90,000	60,000
7. Coal burned per mile, pounds	450	340	270	210	170	120
8. Coal burned per trip, pounds	67,500	51,000	40,500	31,500	25,500	18,000
9. Water used per trip, gallons	50,700	38,300	30,400	23,600	19,100	13,500
10. Cost of coal, per trip	$33.75	$25.50	$20.25	$15.75	$12.75	$9.00
11. Cost of water, per trip	5.07	3.83	3.04	2.36	1.91	1.35
12. Cost of lubrication, per trip	.50	.50	.50	.50	.50	.50
13. Cost of supplies, per trip	.20	.20	.20	.20	.20	.20
14. Cost of repairs, per trip	30.00	27.00	23.28	19.50	15.75	12.00
15. Allowance for renewals, per trip	1.50	1.50	1.50	1.50	1.50	1.50
16. Pay of enginemen, per trip	25.20	25.20	25.20	25.20	25.20	25.20
17. Cost of handling, per trip	2.00	2.00	2.00	2.00	2.00	2.00
18. Interest allowance, per trip	4.10	4.10	4.10	4.10	4.10	4.10
20. Cost of train supplies, per trip	2.25	2.25	2.25	2.25	2.25	2.25
21. Cost of car repairs, per trip	31.50	27.00	22.50	18.00	13.50	9.00
22. Pay of trainmen, per trip	28.98	28.98	28.98	28.98	28.98	28.98
23. Cost of movement, per trip	165.05	148.06	133.80	120.34	108.64	96.08
24. Cost per 1,000 ton-miles, net	.79	.82	.89	1.00	1.21	1.60
25. Million ton-miles, per engine, per month	3.69	3.16	2.63	2.11	1.58	1.05

from table A. Line 21 was figured at 15 cents per 1,000 ton-miles. Thus, $210 \times .15 = 31.50$, and line 22 was taken directly from table A. As before, line 23 is the sum of lines 10 to 22 (as in table C), and the costs in line 24 are the quotients of 24 and 3, thus $\frac{165\ 05}{210} = .79$. Line 25 has been computed as in table A, and is proportional to the values in line 3.

This process is repeated for speeds of 10, 15, 20, 25 and 30 miles an hour, and we are then able to produce table D, in which the upper figures indicate the cost in dollars per 1,000 ton-miles, back of tender, and the lower figures the millions of ton-miles hauled per engine per month for the corresponding loads and speeds found upon the left-hand column and the top line.

TABLE D.—*Cost per 1,000 Ton-Miles in Dollars and Million Ton-Miles per Engine Month.*

	Miles per hour					
	5.	10.	15.	20.	25.	30.
400 tons back of tender...	1.60 / 1.05	1.11 / 1.87	1.05 / 2.54	1.10 / 3.08	1.15 / 3.54	1.25 / 3.92
600 tons back of tender...	1.21 / 1.58	.90 / 2.81	.85 / 3.81	.91 / 4.63		
800 tons back of tender...	1.00 / 2.11	.78 / 3.76	.79 / 5.08	.86 / 6.18		
1,000 tons back of tender...	.89 / 2.63	.72 / 4.70	.76 / 6.35			
1,200 tons back of tender...	82 / 3.16	.70 / 5.63				
1,400 tons back of tender...	.79 / 3.69	.75 / 6.57				

These costs are based on coal at $1 per ton, but any other price would be handled in the same way.

In order to show the effect of speed and weight of

train upon cost and haulage capacity graphically Fig. 11 is presented, which, it is believed, gives the clearest possi-

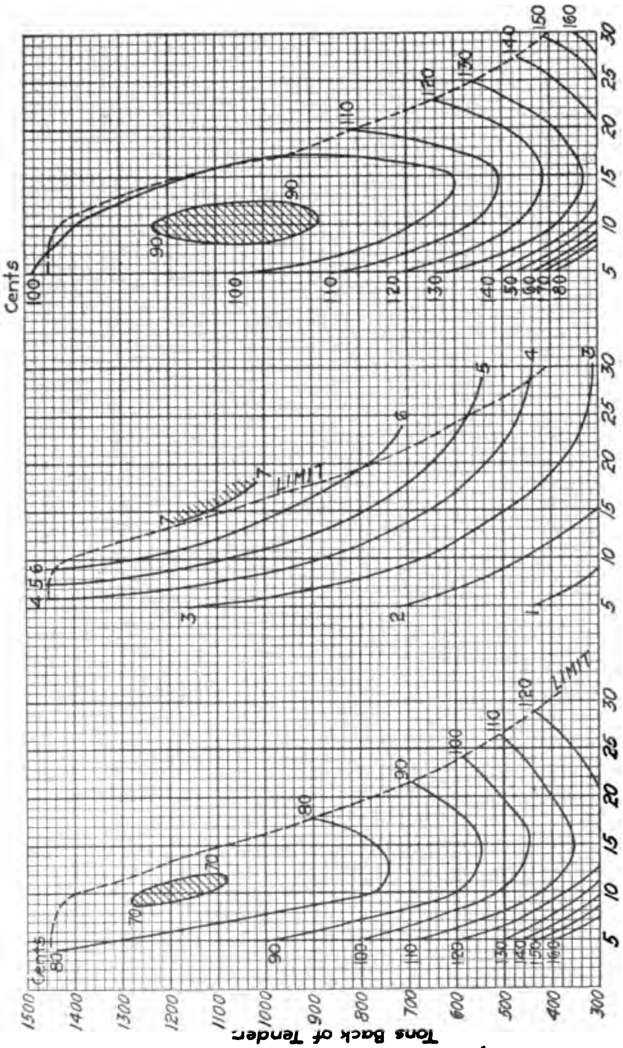


Fig. 11—Diagram Showing the Effect of Speed and Weight of Train Upon Cost and Hauling Capacity.

ble illustration of this very important problem. The left-hand diagram gives the cost in cents per 1,000 ton-miles

(back of tender), with coal at $1 per ton, and, of course, for the engine and grade selected. The right-hand diagram shows the same when coal is $2 per ton. The center diagram gives the hauling capacity in millions of ton-miles per month for a locomotive. In all these the speed is shown by the abscissæ (as indicated at the bottom), and the train load by the ordinates, as seen at the left side of sheet. The cost in cents (in the side diagrams) is indicated by the contour lines, that marked 70 corresponding to 70 cents per 1,000 ton-miles, etc. The lowest point or "valley" is cross-hatched. Thus, if we wish the cost (under the conditions which have been assumed) to haul a train of 800 tons at five miles an hour, we find that the intersection of the five-mile vertical line and the 800-ton horizontal line is crossed by the contour line marked "100" cents, which means that the transportation covered by the accounts mentioned in table A will cost $1 per 1,000 ton-miles, thus agreeing with table D. For a train of 400 tons at 20 miles an hour we find a cost of $1.10 (1·10 cents), also agreeing with table D. The broken line marked "limit" indicates the maximum speed at which any given load can be hauled. For the conditions covered by the left-hand diagram it is evident that the greatest economy for any definite speed requires that the train be as heavy as the engine can haul "at that speed," except in the portions above the shaded "valley of minimum cost."

We found in table D that the minimum cost was obtained with 1,200 tons at 10 miles an hour, and this point in Fig. 11 is in the center of the "valley." As might be expected, there is little change effected by a variation of 100 tons either way, but a very marked difference is caused by a change in speed of three or four miles per hour. For instance, with 1,200 tons, if the running speed be reduced to six miles an hour, the cost will be 80 cents per 1,000 ton-miles. A higher speed will also increase the cost of transportation.

In table A, which gave maximum loads only, it was seen that 15 miles an hour with 1,100 tons was the most economical combination. However, table D indicated that the greatest economy was not at a maximum or full load, and Fig. 11 explains this. We also notice that the most economical speed for any possible train load lies between 10 and 15 miles an hour, the lighter the train the higher being the point of economical speed. If we pass away from this speed, the cost rises rapidly, either for slower or faster runs.

Again, if for the dead freight we haul 1,200 tons at 10 miles an hour, the cost will be 70 cents per 1,000 ton-miles. If, however, the nature of the merchandise calls for a speed of 25 miles an hour, we must cut our rating to 560 tons, and the cost will be about $1.03, which is the lowest possible for that speed, as any further reduction in load would increase the cost. If the speed for this load were only eight miles an hour, the cost would be the same, but at 15 miles an hour it would be about 90 cents.

The value of this diagram is at once apparent, as a superintendent can decide from it what load and speed to adopt, if both are left to his discretion, or if a definite running speed be demanded, the most economical load is at once found. If for special reasons a reduced load must be given engines (as in order to get them over the road) then the best schedule to make for them is also immediately obtained. Of course, such a diagram must be constructed for the particular locomotive and the physical characteristics of the division, but this can be readily done by following the processes above described.

The right-hand diagram (for coal at $2 a ton) shows similar characteristics, but the lowest cost is now about 90 cents per 1,000 ton-miles. It is still at 10 miles per hour and extends from 900 to 1,200 tons back of tender. As the train load decreases the minimum cost requires a speed of 15 miles an hour. The effect of the price of coal is also shown at high speeds. For instance, at $1 per ton,

a speed of 20 miles and a load of 500 tons will cost $1, and with $2 coal $1.20 per 1,000 ton-miles. In general the cost is from 15 to 20 cents greater.

The central diagram shows contours of millions ton-miles per month. Without exception the maximum ton-mileage for any train load is at the highest speed, and at any speed is with the greatest load, as it obviously should be. The especial point of interest is that, however, at which the maximum results can be obtained. This is particularly important in time of congested traffic. It is seen that for the conditions which we have been assuming a load of 1,150 tons and a speed of 14 miles an hour will result in the greatest freight movement that can be brought about. It is probable that ordinarily an engine of the size selected would be given a train load of 1,430 tons. The total monthly movement per engine would be about 6,500,000 ton-miles; if the load and speed were set as above indicated 7,000,000 ton-miles could be made.

Perhaps the most interesting feature of Fig. 11 is the close correspondence of the points of minimum cost and maximum capacity. In the case of dollar coal the best arrangement for cost is 1,200 tons at 10 miles an hour. In the center diagram the greatest hauling capacity is found with 1,200 tons at 13 miles an hour. We also see that for the same cost, viz.—70 cents per 1,000 ton-miles—we can move either 5,000,000 ton-miles per month by hauling 1,280 tons at nine miles an hour, or 6,000,000 per month by taking 1,100 tons at 12 miles an hour. In other words, by properly selecting the train load and scheduling the run we can operate at the minimum cost and very near the maximum engine capacity, considering the total monthly movement. When the full import of this diagram is understood, we believe that every division superintendent in the country would find it to the advantage of his company to have such a chart prepared, and that by following its suggestions he could considerably reduce his cost of operation.

UP AND DOWN HILL.

Instead of a continuous slope in one direction only, let us consider a division of 150 miles, with a summit at the middle. This will, perhaps, be nearer to existing cases than the former supposition. The same locomotive will be selected for our calculations, and we will also assume that the down-hill trip or portion will be run uniformly at 30 miles an hour. The grade of 1 per cent. will be ample to maintain this velocity without any assistance from the engine—indeed, the brakes will have to be used to prevent the train running away. From this it is apparent that on the down-hill part only sufficient coal and water need be used to run the air-pump and make up for radiation. The former would require only about 10 cents' worth of coal for the 75 miles down grade, and the latter would be the same no matter what the train load. From this it is evident that we can, without sensible error, consider that coal and water will be used on the 75 miles of up-hill only. As both sides are 1 per cent. we can refer largely to table A and proceed to construct table E.

Line 1 gives the running speed for the up-grade portion, same as in table A, and, of course, lines 2 and 3 will be the same as in table A. Line 4, the running time between terminals, will be half of that in table A (75 miles up hill) plus $2\frac{1}{2}$ hours, as at 30 miles per hour that time will be required to come down the last 75 miles from the summit; thus $\frac{30}{2} + 2.5 = 17.5$, etc. In line 5 we have added 20 per cent., as before, to the values in line 4. The average speed between terminals, line 6, is 150 miles, divided by line 5, and we notice that these values are all higher than formerly, except in the last column, which is the same for both.

Lines 7, 8 and 9 need not be extended, as we can take the cost for coal and water at one-half that given in table A, in consequence of considering that steam is required

TABLE E.

1.	Speed up hill, miles per hour	5	10	15	20	25	30
2.	Weight of train, tons back of tender	1,450	1,430	1,100	800	560	400
3.	Ton-miles per trip, back of tender	217,500	214,500	165,000	120,000	84,000	60,000
4.	Running time, hours between terminals	17.5	10.0	7.5	6.25	5.5	5.0
5.	Actual time, hours between terminals	21.0	12.0	9.0	7.5	6.6	6.0
6.	Average speed between terminals	7.2	12.5	16.7	20.0	22.7	25.0
10.	Cost of coal, per trip	$18.75	$30.00	$20.25	$15.00	$12.00	$9.37
11.	Cost of water, per trip	2.80	4.50	3.05	2.25	1.80	2.40
12.	Cost of lubrication, per trip	.50	.50	.50	.50	.50	.50
13.	Cost of supplies, per trip	.20	.20	.20	.20	.20	.20
14.	Cost of repairs, per trip	16.50	16.50	13.88	10.85	9.00	7.88
15.	Allowance for renewals, per trip	1.50	1.50	1.50	1.50	1.50	1.50
16.	Pay of enginemen, per trip	14.70	10.50	10.50	10.50	10.50	10.50
17.	Cost of handling, per trip	2.00	2.00	2.00	2.00	2.00	2.00
18.	Interest allowance, per trip	2.60	1.70	1.40	1.25	1.10	1.10
20.	Cost of train supplies, per trip	2.25	2.25	2.25	2.25	2.25	2.25
21.	Cost of car repairs, per trip	32.60	32.10	24.80	18.00	12.00	9.00
22.	Pay of trainmen, per trip	16.90	12.08	12.08	12.08	12.08	12.08
23.	Cost of movement, per trip	111.30	113.83	92.41	70.38	65.53	58.78
24.	Cost per 1,000 ton-miles, net	.51	.53	.56	.64	.78	.98
25.	Million ton-miles, per month	6.00	9.05	8.50	6.80	5.20	3.09

With Reduced Train-Loads, Cost and Ton-Mileage.

400 tons	$\frac{1.02}{1.66}$	$\frac{.86}{2.54}$	$\frac{.87}{3.08}$	$\frac{.89}{3.46}$	$\frac{.93}{3.73}$	$\frac{.96}{3.93}$
600 tons	$\frac{.78}{2.48}$	$\frac{.67}{3.72}$	$\frac{.69}{4.63}$	$\frac{.71}{5.19}$		
800 tons	$\frac{.65}{3.31}$	$\frac{.58}{5.08}$	$\frac{.60}{6.17}$	$\frac{.64}{6.90}$		
1,000 tons	$\frac{.58}{4.15}$	$\frac{.52}{6.36}$	$\frac{.56}{7.73}$			
1,200 tons	$\frac{.54}{4.98}$	$\frac{.50}{7.62}$				
1,400 tons	$\frac{.51}{5.80}$	$\frac{.52}{8.90}$				

on the 75 miles of up-grade only. Lines 10 and 11 are, therefore, given at one-half the previous values in table A. Lines 12 and 13 follow table A without change, as they are based on engine mileage only. Line 14 is one-half of that in table A plus 75 cents, thus $\frac{31.50}{2} + .75 = 16.50$, as the tractive effort will be identical for 75 miles (half the distance), and the last 75 miles being run without steam, only 1 cent a mile will be charged.

Line 15, renewals, being based on engine mileage, will remain unchanged. As the average speeds are now greater, we shall have a reduction in the pay of enginemen (line 16) in the first two columns, but after that the amounts will be the same, being based on mileage only. The cost of handling (line 17) will, of course, remain as before. The time of trips being shorter, line 18, interest, will be less, except in the last column, it being computed at 10 cents an hour for the same time of trip, plus five hours for lay-over.

Lines 20 and 21, train supplies and car repairs, will remain as before, but line 22, pay of trainmen, will reduce in a manner similar to that of enginemen, and for the same reason. Lines 23, 24 and 25 were computed in the same manner as in table A, and the effect of the 75 miles of down grade is at once apparent in the reduced cost and greater movement per month.

By a process as explained in connection with tables C and D, the lower portion of table E has been calculated, and the results laid off for graphical inspection in Fig. 12. As before, we have our minimum cost at about 10 miles an hour running speed up grade, but while in the previous case this corresponded to an average speed between terminals of 8.3 miles an hour, it now means 12 miles an hour (as shown by the upper speed figures), or an average running time of 15 miles an hour. The cost is

50 cents per 1,000 ton-miles, instead of 70 cents, and this is the lowest possible figure attainable by any combination of speed and load. (This would correspond to about 3 mills per revenue ton-mile if all expenses were included, but no light engine mileage or empty hauls had to be paid for.)

The total movement per engine month is shown by the right-hand diagram. Here the highest possible figure is 9,000,000 ton-miles a month, which is, however, only two-sevenths greater than in the former case. The crossed dot indicates that the best results, considering both cost and movement, can be obtained by loading to 1,300 tons (150 tons less than the full load for the engine) and running up hill at 11 miles an hour, or average speed including 20 per cent. of delays of 13 miles an hour. Under these conditions the cost would be about 51 cents per 1,000 ton-miles and about 8,500,000 ton-miles (back of tender) could be taken by each engine per month.

The cost of fast freight and stock trains is again apparent. If a train is to average 25 miles an hour we see that the cost will be $1 per 1,000 ton-miles—double what was possible with slow freights, and only about half as much tonnage could be moved per month. Again, if engines are loaded, as they in all probability would be, with 1,450 tons, the average speed would be 10 miles an hour, which would ordinarily be considered quite fair; but if a congestion of traffic occurred by diminishing the load 10 per cent., or to 1,300 tons, 1,500,000 ton-miles more could be made a month, and the cost of movement actually decreased. This being the case there is little to recommend the extreme load for ordinary operation, except for the personal satisfaction of making a paper record and endeavoring to please the "man higher up" who may happen to be so thoroughly imbued with the advantage of a big train load, that the real cost of operation has been overlooked by him.

UNDULATING PROFILES.

It often occurs that a division lies across country—that is, over ridges of hills—and so makes a "saw-tooth" profile. Let us consider 150 miles as before, divided into 10-mile stretches of 1 per cent. grade up, 1 per cent. down and level; that is, there may be 10 miles of level track, followed by 10 miles up hill and the same distance down grade, this sequence repeated five times over the division. This will constitute an undulating profile and we should see what effect the level stretches will produce.

By means of the thin sheets, Figs. 7 to 10, we can determine the coal consumption in connection with Fig. 2, also the maximum speed which different loads can be taken on a level. In a similar manner we will calculate the cost of trips running up hill at speeds of 5, 10, 15 and 20 miles an hour, with train loads of 800 tons and upward to the capacity of the engine. We will assume that all downhill movements are made at 30 miles an hour, and on the levels a speed as great as the train load will permit. When we use the greatest load that can be taken up the 1 per cent. grades at the speeds considered, viz.—1,450, 1,430, 1,100 and 800 tons, respectively—we find that the engine can make on a leved 32, 33, 37 and 42 miles an hour accordingly. With lighter trains higher speeds can be obtained. By taking these various factors into account we were able to produce Fig. 13, in which the curves have not been extended to quite as light trains as in Fig. 12. We are at once struck by the fact that the minimum cost curve (46 cents) is confined to the five miles an hour uphill line—the average speed between terminals is, however, nearly 10 miles an hour, or a running speed averaging 12 miles an hour, if the lay-over allowance be extinguished. The cost is generally reduced from 3 to 5 cents per 1,000 ton-miles, and the rate of increase for higher speeds is not so great.

The right-hand diagram shows nearly 2,000,000 ton-

miles per month more work done for the same up-grade speeds and loads, but nearly the same for comparative average speeds, as we should expect. The principal dif-

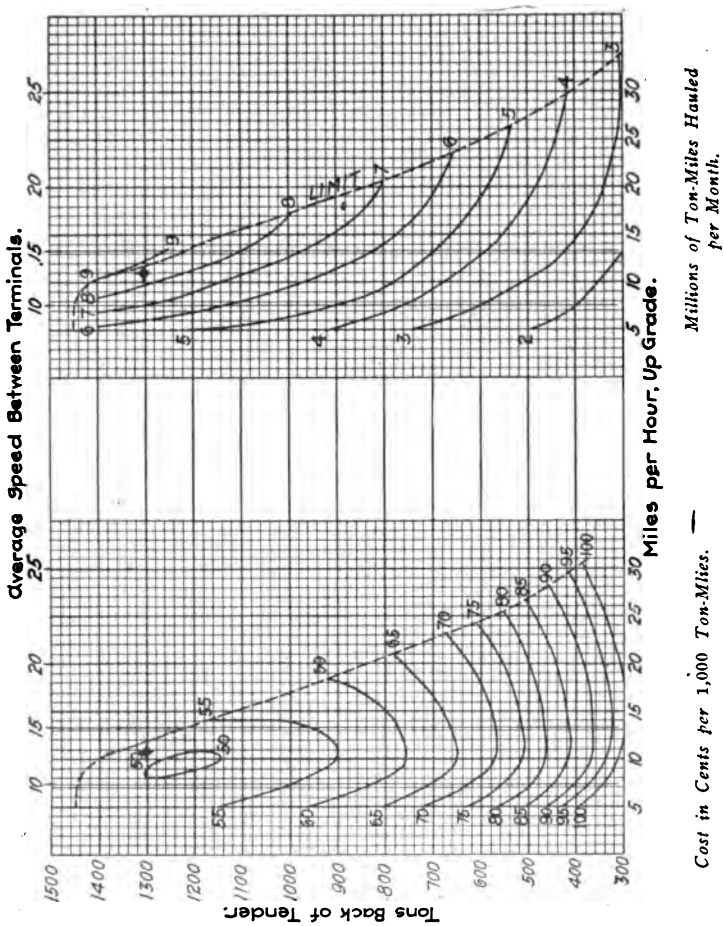
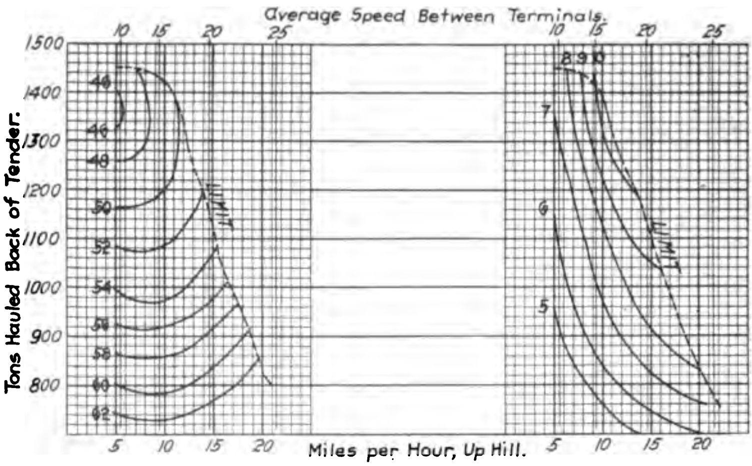


FIG. 12—RESULTS OF LOCOMOTIVE OPERATION.

ference is in the wide separation of the schedules of minimum cost and maximum work. In Fig. 12 there is only about two miles an hour difference in speed between

these two combinations. In Fig. 13 there is about seven miles difference in average speed, and the variation in cost is about 4 cents instead of 2 cents.

We again see that the most economical rating is not the maximum which the engine can haul on the hills, but is slightly less, perhaps 100 tons. In general the characteristics are similar for Figs. 11, 12 and 13, but there is sufficient difference to indicate the importance of having a chart made for each operating division, embodying the peculiar physical characteristics of each.



Cost in Cents per 1,000 *Ton-Miles.* *Millions of Ton-Miles Hauled per Month.*

FIG. 13—RESULTS OF LOCOMOTIVE OPERATION.

Figs. 12 and 13, indicating that the most economical and also most efficient (capacity) speed is about 12 miles an hour between terminals are corroborated by the recent tests of one of the largest railroads in this country, from the results of which it was found that 12 miles an hour (between terminals) gave the minimum cost per car mile and also the maximum car mileage per engine month. Other roads have lately found the same to be true, though little has been printed on this fact.

COMPARATIVE COSTS.

It often occurs that the comparative cost of operating over different profiles is desired. This may be needed in order to determine the wisdom of constructing a new line over a lower grade, or of altering an existing one. For instance, a survey is being made in order to connect two points 150 miles apart on practically the same level above the sea. One line can be built for a certain sum, but necessitates a 1 per cent. grade each way from a central summit; another line, more costly, can be built with one-half per cent. grades each side of the central summit. The question then arises: "Will the reduced cost of operation pay a sufficient interest on the increased cost of construction for the low-grade line?"

Table E gave us the cost per 1,000 ton-miles for all combinations of speed and train load, and it appeared that 1,200 tons at an average speed between terminals of 12½ miles an hour could be transported at 50 cents per 1,000 ton-miles, including the operating charges embodied in items 10 to 22 inclusive.

Table F gives the same information (condensed) for the second case mentioned above—that is, a 150-mile division with central summit approached by one-half per cent. grades. We again find the lowest cost in the column corresponding to an average speed of 12½ miles an hour, and with a train of 2,200 tons back of tender it amounts to 35 cents per 1,000 ton-miles. There would evidently be a saving of $50 - 35 = 15$ cents for each 1,000 ton-miles hauled back of tender, but as this includes the deadweight of cars, which may be as great as the revenue load, we should conclude that 30 cents per 1,000 revenue ton-miles might be saved by such grade reduction. It is evident that the other charges, such as superintendence, maintenance of track, etc., would be little affected by the easier profile, so that the question resolves itself into one of traffic density. If a traffic of 1,500,000

TABLE F.

1. Speed up hill, miles per hour.	5	10	15	20
2. Weight of train tons back of tender	2,550	2,530	1,900	1,350
3. Ton-miles per trip, back of tender	383,000	380,000	285,000	202,000
4. Running time, hrs. bet. terms.	17.5	10.0	7.5	6.25
5. Actual time, hrs. bet. terminals	21.0	12.0	9.0	7.5
6. Average speed, bet. terminals.	7.2	12.5	16.7	20.0
24. Cost, per 1,000 ton-miles, net.	$0.36	$0.37	$0.39	$0.43
25. Million ton-miles per month..	10.6	16.1	14.7	11.6

With Reduced Train Loads, Cost and Ton-Mileage.

1,200 tons.	$\frac{.47}{5.0}$	$\frac{.42}{7.6}$	$\frac{.43}{9.3}$	$\frac{.45}{13.3}$
1,400 "	$\frac{.44}{5.8}$	$\frac{.40}{8.9}$	$\frac{.41}{10.8}$	
1,600 "	$\frac{.41}{6.6}$	$\frac{.37}{10.1}$	$\frac{.39}{12.3}$	
1,800 "	$\frac{.39}{7.5}$	$\frac{.36}{11.4}$	$\frac{.38}{13.8}$	
2,000 "	$\frac{.37}{8.3}$	$\frac{.35}{12.7}$		
2,200 "	$\frac{.36}{9.1}$	$\frac{.35}{13.9}$		
2,400 "	$\frac{.35}{9.9}$	$\frac{.36}{15.2}$		

revenue ton-miles per day could be depended upon, the saving per day would be $1,500 \times .30 = \$450$, or for 300 days, $135,000 per year. If money could be borrowed at 4 per cent. interest, this would represent a cash capitalization of $3,375,000, up to which amount the low-grade line would be a paying investment. If the traffic were greater, then we could afford to spend still more in perfecting the line. There is still another advantage for the low-grade location, and that is, that each locomotive could haul nearly double the ton-mileage each month, so that only about half as many engines would be needed to do a given amount of work.

There is considerable labor in calculating tables E and F, and if we wish to know the difference in cost of operating on two profiles, it will ordinarily be sufficiently close to simply figure the cost per 1,000 ton-miles at the maximum load which the engine can haul. Thus in table E we find this to be 51 cents (see line 24, five-mile column) and in table F, 36 cents. The difference is again $51 - 36 = 15$ cents, precisely the amount found by the more laborious method of calculating various combinations of weight of train and speed. While the heaviest trains and slowest speeds do not give the minimum cost, as is apparent from Figs. 11, 12 and 13, yet as a rule the cost of transportation is not greatly in excess of the minimum, where the engine is so loaded, and for quick results figures based on maximum train loads will frequently be found useful, especially for comparisons; but when decisions are to be made as to the actual schedule and loading to be adopted, then the advantages of charts showing the cost and quantity of freight moved will be very great.

STOPPING AND STARTING.

Our analysis would hardly be complete if we did not consider the often discussed problem—the cost of making a stop. In the chapter on fuel we determined the amount

of coal necessary for stopping and starting a train of 2,000 tons back of tender on a level track. This was found to be 213 lbs. greater than would have been burned if the train had continued moving uninterruptedly at a speed of 27 miles an hour, which was the maximum speed possible under the assumed conditions. We also found that the stop would require 16 seconds of time and 320 ft. of distance, while to accelerate the train to 27 miles an hour again would require 10 minutes and 34 seconds and 19,113 feet, or a total loss of 10 minutes and 50 seconds (without allowing any time for remaining stationary). The amount of water corresponding to this quantity of coal would be three-quarters of 213, or 160 gallons. Items 12 and 13 would evidently not be affected under our methods of analysis.

The cost of locomotive repairs would be increased, as the draw-bar pull would be greater during acceleration than when running uniformly at 27 miles an hour. In the latter case the draw-bar pull or tractive force would be about 19,000 lbs., or 9½ tons, so that the cost would be $9\frac{1}{2} + 1 = 10\frac{1}{2}$ cents per mile. During acceleration this force would probably average 30,000 lbs., or 15 tons, and the corresponding cost would be 16 cents per mile, the difference being 5½ cents. As the distance through which acceleration takes place is over 19,000 ft. we can call it four miles, making an increased cost of $4 \times 5\frac{1}{2} =$ 22 cents for wear and tear on the engine.

The pay of enginemen will be increased under some conditions. Thus, if the average speed for the trip is less than 10 miles an hour and the 11 minutes lost by this stop is not made up, it will appear as overtime. If it be made up, or if the average speed, with stop included, still exceeds 10 miles an hour, then no overtime will be called for. We are now considering, however, that the time lost by stopping is not made up and must be paid for as overtime. Then at 70 cents per hour we shall have $\frac{11}{60} \times 70 =$

13 cents; so, for the trainmen at 80.5 cents an hour, we have $\frac{11}{60} \times 80.5 = 15$ cents. As interest was assumed at 10 cents an hour, the excess will be 2 cents.

We can now tabulate these extras as shown below:

Coal, 213 lbs. at $1.00 per ton	$0.10
Water, 160 gallons at 10 cts. per 1,000	.02
Repairs, 4 miles at 5½ cts.	.22
Enginemen	.13
Interest	.02
Trainmen	.15
Total	$0.64

There should properly be added an amount representing the wear of brake-shoes, wheels, etc., but no data is at hand for this purpose; in a general way it is covered in regular repair charges. Still, it must be excessive and abnormal at such times, and the money value has been variously estimated at from 9 to 15 cents a stop. If we allow for this, it would put our cost at 75 cents under the conditions which we have considered.

In October, 1905, Mr. J. A. Peabody gave some estimates of cost of stopping trains in a paper presented at the annual meeting of the Railway Signal Association. These were generally what might be called "high-class guesses," but as they were made by competent railroad officials they are worthy of consideration. The values given were as follows:

Passenger trains,	530 tons,	50 miles speed		$0.42
Freight trains,	2,000 "	35 "	"	1.00
Passenger trains,	400 "	45 "	"	.35
Freight trains,	1,500 "	15 "	"	.56

It would appear, therefore, that the amount shown by our calculations, viz.—75 cents—corresponds closely with what might ordinarily be expected by railroad officials, even if the individual items composing this amount do not agree in detail. It is evident that the

method just discussed will give different results for different conditions of train load, grade, etc., but it is perfectly proper that this should be so. As with all questions of operating costs, it would be extremely difficult, if not impossible, to compute accurately the cost of any definite stop, yet we have here the elements which evidently enter into the problem, and they will surely affect the total figures in accordance with their relative importance. It is believed that the results will be sufficiently accurate and reliable for all practical purposes, and especially so for making comparisons, which, it has been stated before, was the particular object sought to be accomplished by this study.

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